The Challenges & Opportunities of Using Low Carbon Energy Supplies & Their Application to the Developing World

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Declaration

This thesis is submitted to the University of Warwick in support of my application for the degree of Doctor of Philosophy. It has been composed by myself and has not been submitted in any previous application for any degree apart from parts of Chapter 1.2.2, which have featured previously in a dissertation submitted by myself as partial fulfilment of the requirements for a Master of Science by research at the University of Warwick.

Publications

The following publications have arisen from aspects of the work described in this thesis:

From Chapter 2:

Blenkinsopp, T., Coles, S. R. & Kirwan, K. (2013). Renewable energy for rural communities in Maharashtra, India. Energy Policy 60, 192-199.

From Chapter 3:

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Summary

Chapter Two provides a review of current literature assessing the current state of modern energy provision in developing countries and the impact it has on facilitating sustainable development. The use of low carbon energy sources is also explored with the review highlighting the benefits they offer over traditional mean of energy generation as well as the barriers that exist to their uptake.

Chapter Three outlines the thesis aims and objectives, and provides an overview of the different methods and approaches employed to accomplish them.

Chapter Four presents the results for the completion of a rural energy survey completed in Maharashtra, India. The survey explored current energy requirements, as well as the attitudes towards modern energy sources with particular focus on renewable and sustainable sources, to identify the opportunities and barriers for their expanded use.

Chapter Five explores the energy requirements and attitudes towards modern energy services of a larger rural population sample in Orissa, India. The similarities and differences between the two studies are also identified.

Chapter Six describes the application of statistical techniques to analyse the result of Chapter five to identify factors which may be associated with a respondents attitude towards modern energy provision via renewable energy sources, which could potential be used as indicators to identify and target groups to reduce barrier and improve acceptance of RETs.

Chapter Seven outlines the potential environmental impacts which can be associated with a decentralised RET system resulting from the use of standalone energy storage systems. The suitability and impacts of specific chemical storage system are explored through a life cycle assessment. The potential of using repurposed batteries is also examined.

Chapter Eight details the modelling of household energy use in rural India to determine the wider environmental impacts of the uptake of RETs. The environmental benefits of substituting current means of energy provision with RETs are assessed, and the effects introduction of RETs has on national total energy demand and primary fuel consumption are explored.

Chapter Nine provides a summary of the key findings and conclusions of this thesis and outlines recommendations for the process by which a RET system for energy provision can be successfully introduced in rural communities of developing countries.

Abbreviations

ANOVA	Analysis of Variance
CDM	Clean development mechanism
CER	Certified mission reduction
CFCs	Chlorofluorocarbons
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
DFID	Department for International Development
EOL	End of life
FET	Fisher's Exact Test
GHG	Greenhouse gas
GWP	Global warming potential
HFC	Hydrofluorocarbons
IEA	International energy Agency
IPCC	Intergovernmental Panel on Climate Change
LCA	Life cycle assessment
LCT	Low carbon technology
LDA	Linear Discriminant Analysis
LEAP	Long-range Energy Alternatives Planning system
Li-ion	Lithium ion
LPG	Liquid petroleum gas
MDG	Millennium Development Goals
N_2O	Nitrous oxide
NGO	Non-governmental organisations
NiCd	Nickel-cadmium
NiMH	Nickel-metal hydride
NO_x	Mono-nitrogen oxides
OPEC	Organisation of the Petroleum Exporting Countries
PbA	Lead-acid
PM	Particulate matter
ppm	Parts per million
PV	photovoltaic
RET	Renewable energy technology
SPSS	Statistical Package for the Social Sciences
t	Tonnes
UNDP	United Nations Development Programme
VOC	Volatile organic compounds

Chapter 1. General Introduction

This thesis is concerned with the use of low carbon technologies as a means of delivering modern energy services in developing countries and the impact they can have on facilitating sustainable development.

The desire for universal access to modern energy services and the use of alternative technologies as a means of delivering low carbon energy are driven by several local and global factors.

Some of the key factors arise from concerns surrounding the ever growing global population, future energy security and the continuing impacts and challenges faced as a result of climate change. All of these factors are associated with a range of environmental, social and economic impacts.

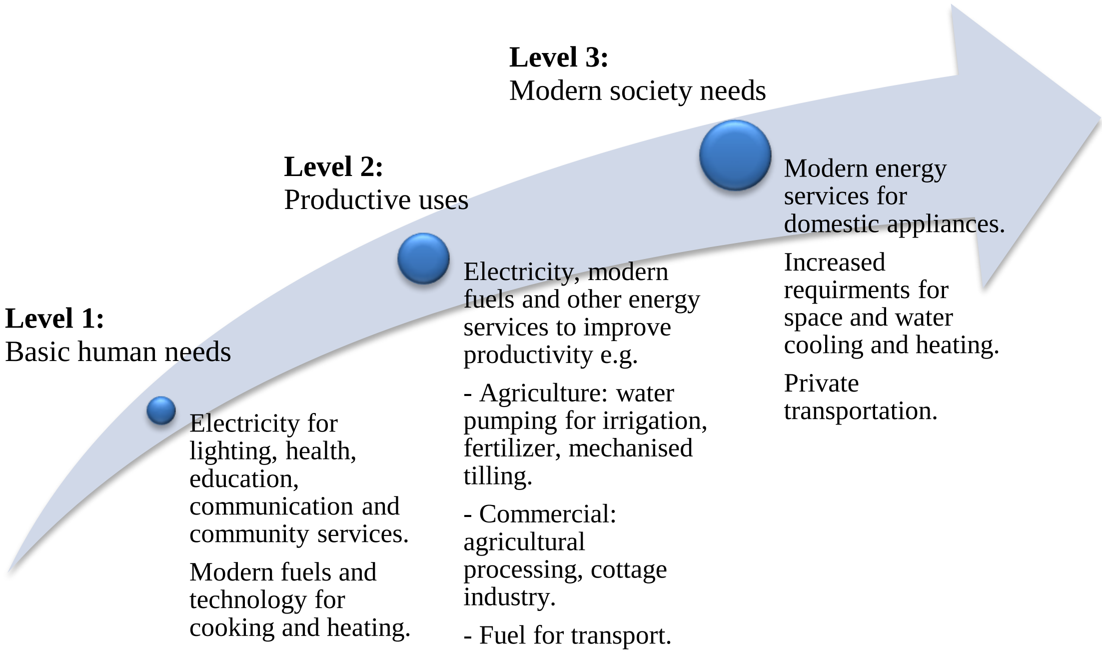
This chapter provides an introduction to the current state of modern energy provision, the benefits it offers as well as the negative impacts current means of provision are resulting in. Furthermore an overview is provided of the alternative options that are available and the factors which are driving their uptake.

1.1. The Need for Modern Energy

At the centre of the most critical economic, environmental and developmental challenges facing the world today is energy (UN-AGECC 2010). The energy requirements of humans are encompassed by electricity, heat, light and mechanical power which can be sourced from a wide range of fuels (DFID 2002a).

The UN Advisory Group on Energy and Climate Change (UN-AGECC) defines modern energy access as *'access to clean, reliable and affordable energy services for cooking and heating, lighting, communications and productive uses'* (UN-AGECC 2010). They also outlined three levels of energy access; 1) basic human needs, 2) productive uses and 3) modern society needs (UN-AGECC 2010). Levels 1 and 2 represent what needs to be achieved in order to meet the UN-AGECC definition of modern energy access (UN-AGECC 2010) Figure 1.1 shows the incrementing levels of energy access.

Figure 1.1: The three incremental levels of energy access and their associated services (Adapted from UN-AGECC 2010).



There is however no universally accepted definition for what modern energy access encompasses. The International Energy Agency (IEA) for instance defines it simply as *"household access to electricity and clean cooking facilities"* (IEA *et al.* 2010) which although complements the definition of basic human needs under the UN-AGECC incremental scale, is much narrower in its scope.

This work is in agreement with the UN-AGECC and its broader definition of energy access. Modern energy access is defined as the energy for basic services and productive uses which represent the minimum level of access required to improve living standards in the poorest countries and help drive sustainable economic development (UN-AGECC 2010). This in turn should lead to long term benefits and stability.

The UN-AGECC definition also states that access should be 'affordable' which is an important factor as this ensures that the cost to the end user are compatible with their income (UN-AGECC 2010). Uptake would not be universal if the costs exceeded those of traditional fuels. In many cases this may require the implementation of subsidies in the short term before economic development enables the user to become self-reliant in meeting their energy requirement (UN-AGECC 2010).

1.2. Benefits Of Modern Energy Access

Access to modern energy can have a profound impact upon peoples' lives through the 'services' it provides and its contribution to development. It is essential in the provision of nearly all aspects of human welfare (Nussbaumer *et al.* 2012, UNDP 2005a), including sanitation, healthcare, clean water, agricultural productivity, education and sustainable development (DFID 2002a, IEA *et al.* 2010, UNDP 2005a). It is however predominantly the benefits or 'services' gained through energy access that people desire (DFID 2002a). These include reliable and safe lighting, heating and cooking facilities, as well as mechanical power and telecommunication services (IEA *et al.* 2010, UNDP 2005a). It is these benefits that drive the demand for energy not the desire for energy itself (DFID 2002a).

The benefits that modern energy access can offer are particularly seen in developing countries and the poorest communities within them. Often people in these communities lack access to electricity and are reliant upon traditional biomass for cooking (IEA *et al.* 2010). The provision of modern energy access can drastically improve the living conditions of these people and stimulate development within the country. 'Access' is however a far more complex component of household energy security with the quality, availability and affordability all playing a part (Rao 2013).

1.3. Disadvantages Of Modern Energy Access

Despite the noted benefits modern energy access and the services it provides can offer, there are significant downsides which have both national and global implications and stem from the means by which this energy is delivered. In particular the current state of global fossil fuel dependency and the challenges being faced by climate change.

Global Fossil Fuel Dependency

Fossil fuels account for approximately 87.0% of the world's primary energy consumption, the demand of which is set to increase by 51.0% over the next twenty-five years (OPEC 2011). Although the demand for each fossil fuel will increase over this period, their share of the total energy mix will drop to around 82.0%, as the use of alternatives energy sources are expanded (IEA 2011, OPEC 2011).

Oil will remain the dominant energy source for the next two decades, however its share of the total energy mix is predicted to drop from 35.2% to 28.4%, as the use of other fossil fuels (coal and gas) increases (OPEC 2011). Coal will overtake oil as the dominant energy source by 2035, ultimately accounting for 28.5% of the global energy mix. The use of natural gas will increase most quickly, in terms of both volume and percentage of energy mix. Gas consumption is set to increase by 73.0% over the next twenty-five years and will ultimately account for 25.3% of the energy mix by 2035 (OPEC 2011). By comparison oil consumption will increase by 25.0% and coal by 53.0% over the same period (IEA 2011, OPEC 2011)

As with all fossil fuels, the amount of oil available from the earth is finite, and as the demand increases there will be a point at which the conventional oil supply will no longer be capable of supporting the growing global demand as a result of economic growth (Hirsch *et al.* 2005, Odland 2006).

Peak oil is the term used to describe the point at which the production of oil begins to decline. This means that the production of world oil cannot increase after this point and therefore a decline in global oil production will be seen afterwards (Hirsch *et al.* 2005).

It might be the current most popular energy source but as its value increases and availability decreases there will be increased competition for the remaining available fossil fuels, this competition will help to further inflate their value, possibly marginalising poorer developing countries, and threatening their national energy security.

As the production of oil is in decline in 33 of the world's 48 largest oil producing countries (Hirsch 2005), there is much debate over when, or if, this has already occurred on the global scale with several predictions having been made by a range of experts, ranging from 2005 to beyond 2030 (Hirsch 2007, Hirsch *et al.* 2005, IEA 2008, World Energy Council (WEC) 2007) . Deriving an accurate prediction is hampered by the fact that data for oil and gas reserves are unreliable as they are not audited by an independent organisation (Zhang *et al.* 2010).

The Association for the Study of Peak Oil and gas (ASPO) has estimated oil production to peak between 2011 and 2012 at between 90.0m b/d[1] and 94m b/d (Niholls 2008). However, ASPO itself pointed out that these estimates are generous, and may not be reached. Actual output may be more likely to plateau at 84m b/d if the current rate of demand for oil continues at its current rate (Niholls 2008). If the level of demand changes, then the peak might be pushed back as far as 2018, but even with this optimistic approach, the oil peak is forecasted to occur within the next two decades (Niholls 2008).

[1] Million barrels per day

In contrast the Organisation of the Petroleum Exporting Countries (OPEC) have denied the existence of a global peak oil problem (Hirsch 2007) stating in one of its latest outlook on global oil: *"there is enough oil to meet the world's needs for the foreseeable future"* (OPEC 2008). This is most likely because a peak in oil production would affect their control of the market, and thus it is as a result of self-interest that they deny a problem (Hirsch 2007). However, some members of OPEC have warned that a peak in oil production is likely, with the oil supply unable to meet global demands in the next ten to fifteen years (Hirsch 2005).

The main driving force behind the continuing use of fossil fuels comes from the increasing demand of developing countries which is driven by economic growth and development (IEA 2011, OPEC 2011, OPEC 2012, UNDP 2005a, Xia 2003). Although the demand for energy is also increasing in the worlds developed countries, they are expected to meet this with increased use of alternative and renewable energy sources (IEA 2011, OPEC 2011).

In many developing countries the use of traditional biomass as a primary energy source is already widespread (UNDP 2005a); however in order to drive economic development and improve living standards, modernisation of energy services is essential (Demirbas & Demirbas 2007). Forecasts suggest that conventional fossil fuels will be used to achieve this, with the demand for oil, gas and coal predicted to increase approximately 25.0%, 35.0% and 38.0% respectively in developing countries by 2035 (OPEC 2011).

Due to insufficient domestic resources, many countries (not just developing countries) become net importers of fossil fuels in order to meet their energy requirements', which leaves them vulnerable to market instabilities, which can arise from a variety of external factors, such as trade embargoes, political unrest, conflict and variation in production (Andrews 2005, Holm 2005, Ölz *et al.* 2007). These instabilities can lead to price shocks which can affect the macroeconomics of a country and even destabilise whole regions (Bohi 1991, Holm 2005, IPCC 2011).

In some countries, particularly developing countries, this vulnerability will only be further exposed if alternatives to fossil fuels as a means of energy generation are not found to facilitate development. These uncertainties have prompted several countries to consider and prepare alternatives to enable a move away from the need to import fuels (Johnston & Holloway 2007)

Greenhouse Gases & Climate Change

Various human activities result in the release of large amounts of Greenhouse gases (GHGs) into the earth's atmosphere, especially the burning of fossil fuels.

GHGs have a significant effect upon the earth's average temperature. The main GHGs that are produced as a result of human activities are methane (CH_4), nitrous oxide (N_2O), carbon dioxide (CO_2) and halocarbons such as CFCs (chlorofluorocarbons) (Demirbas & Demirbas 2007, Dincer 2000, IPCC 2008, IPCC 2013). These anthropogenic gases each have a different warming effect and each is found in different quantities in the atmosphere. Studies over recent years have shown that the atmospheric concentrations of these gases have been steadily increasing (IPCC 2008, IPCC 2013). According to the 5th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), atmospheric CO_2 concentrations had increased from a pre-industrial level of 278 to 391 parts per million (ppm) by 2011. Similarly the concentrations of CH_4 and N_2O have increase above their pre-industrial levels by 150% and 20% respectively (IPCC 2013).

The concentrations of many halocarbons pre-industry, including CFCs and HFC (hydrofluorocarbons) were near zero, suggesting the increase has been solely due to human activity (IPCC 2008, IPCC 2013). Several report by IPCC have identified with high confidence, that the recent increases in global temperatures are the net result of human activities (Escobar *et al.* 2008, IPCC 2007, IPCC 2013).

The relationship between atmospheric concentration and warming effect is important in determining the effect each gas has on global warming. Table 1.1 shows the warming effect of different GHGs and their atmospheric concentration. CO_2 has the most significant contribution to global warming despite having a very small warming effect because it is the most abundant GHG in the atmosphere. The annual emissions of CO_2 have increased in the last forty years by approximately 80% and in total represents 77% of total anthropogenic GHG emissions (IPCC 2008).

Table 1.1: The Global Warming Potential of different greenhouse gases (IPCC 2013)

Greenhouse gas	Warming effect	Atmospheric concentration (ppm)
Carbon dioxide (CO_2)	1	391
Methane (CH_4)	84	1.8
Chlorofluorocarbons (CFCs)	6,900	<0.01
Nitrous Oxide (N_2O)	264	0.3

GHGs contribute to global warming through the effect they have in the troposphere; they absorb infrared radiation emitted from the earth's surface, which in turn warms the lower atmosphere and surface (Tyler Miller & Spoolman 2008). This natural warming process, which is referred to as the greenhouse effect, is essential to life on earth and without it earth would be a cold and mostly lifeless place (Tyler Miller & Spoolman 2008).

The impacts of global warming have been extensively documented in recent years. These range from increased flooding and freak weather events, to the disruption and shift of terrestrial and aquatic ecosystems, as well as effects on human environments and activities (IPCC 2007, IPCC 2014). The impacts will effect human populations either directly or indirectly, be it through the disruption of food supplies, the destruction of habitat or the emergence of new environmental pressures including diseases and drought (IPCC 2007, Tyler Miller 2007).

Projections have identified impacts that could arise or be exacerbated if the current trend of climate change continues. These include sea-level rises resulting from widespread deglaciation of the Greenland and West Antarctic ice sheets. According to the IPCC a 1-4°C temperature increase will cause a 4-6m sea-level rise (IPCC 2007, IPCC 2008).This in turn will result in the need for widespread relocation of economic centres and populations (IPCC 2007, IPCC 2008),

Global increases in CO_2 have primarily been due to increased use of fossil fuels, such as oil (IPCC 2008, IPCC 2013, IPCC 2014). The increases in CO_2 emissions have been seen as a result of the growth in energy, transport and industry sectors (IPCC 2008).

The effects of global warming also vary from region to region. Some impacts are not always negative and can in rare cases result in positive effects on the local area. However, these are limited and are often outweighed by other negative impacts. The timing and magnitude of an impact will vary with the scale and timing of climate change and will also be influenced by the capacity to adapt (IPCC 2007).

1.4. Low Carbon Energy & Technologies

Low carbon energy is energy that is generated and supplied from sources which result in lower atmospheric carbon emissions in comparison to more traditional or conventional means of energy generation. The technologies that are used to deliver this energy are often referred to as low carbon technologies (LCT). The most widely recognised examples include several forms of modern renewables.

These technologies, in particular the renewable energy technologies (RETs), not only provide a means by which universal modern energy services can be delivered but also offer a sustainable and reliable energy supply that helps contribute to climate change mitigation through reduced atmospheric carbon emissions. RETs also lend themselves to be used for decentralised energy generation allowing increased and improved energy access in remote areas (Thiam 2010).

1.4.1. The Drive To Use LCTs

The current reliance on centralised fossil fuel derived energy has resulted inequalities, environmental degradation and the growth of external national debts (Hiremath *et al.* 2009, Holm 2005). There is growing public and political pressure in favour of using alternative, more sustainable means of energy generation, not only as a way of avoiding many of the environmental problems faced through the use of fossil fuels but also to improve national energy security by reducing the dependency on imported energy sources such as oil (Bull 2001, Escribano Francés *et al.* 2013, Martinot *et al.* 2002, Stigka *et al.* 2014, Swift-Hook 2013, Wang *et al.* 2014a).

The support for using RETs as a source of low carbon energy has been growing within the international community for some time. Many governments and non-governmental organisations (NGOs) are actively promoting and supporting their uptake, particularly in developing countries as a means of alleviating many social and environmental issues (Martinot *et al.* 2002). A decline in the associated costs of these technologies as well as improved efficiency and reliability has also increased interest in using RETs as means of delivering modern energy services (Demirbas & Demirbas 2007).

Chapter 2. Literature Survey of Modern Energy Services & Developing Countries

This chapter will explore the existing literature to assess the current options and benefits of using low carbon technologies to deliver low carbon energy, as well as the barriers to their use, in order to identify suitable technologies which can be used to deliver sustainable modern energy in developing countries. Particular focus will be given to rural energy provision in India as means of improving social and economic conditions.

2.1.1. The Advantages & Disadvantages of RETs

The main advantage of utilising RETs is that they can mitigate many of the impacts of traditional energy generation such as deforestation, climate change and local air pollution. The energy generated from these technologies does not contribute to climate change (as with fossil fuels) as in most cases there is no release of any GHG (Demirbas & Demirbas 2007, Dincer 2000, Nakata *et al.* 2011). Furthermore in the cases where CO_2 is released, the combustion of biomass for example, the carbon emissions are considered neutral, that is that the amount of carbon released is the same as that sequestered during feedstock production (Nakata *et al.* 2011).

Most RET can be used as decentralised or 'off grid' sources of energy, which enables localised energy generation but also enables flexibility in selection of the technology employed and the scale of the project (Bull 2001, Chakrabarti & Chakrabarti 2002, Dincer 2000, Hiremath *et al.* 2009, Mahapatra & Dasappa 2012, Ölz *et al.* 2007). This can allow for the most appropriate RET to be used that will meet the local energy demand but also exploit the local condition. This approach also avoids the 'one scheme fits all' attitude often seen during the provision of modern energy services.

Unlike fossil fuels, RETs are not a finite resource, their renewable nature means they can never be exhausted as they are naturally replenished over a short period (Demirbas & Demirbas 2007). This mean they can provide a reliable and sustainable energy source in the long term that contributes to national energy security by diversifying energy supplies and reducing the need for foreign energy imports (IPCC 2011, Karytsas & Theodoropoulou 2014). Because they essentially constitute being an indigenous energy source, they are less susceptible to outside influences (Ölz *et al.* 2007).

Like all energy sources RETs are not without their limitations. They are in one way or another dependent on the correct conditions in order to function correctly with production rates varying with the conditions (Kousksou *et al.* 2014). Solar collectors require adequate levels of sunshine and clear skies, wind turbines require wind, and hydro energy generation relies upon a consistent water supply to fill dams and reservoirs. When these conditions are not met, the ability to generate energy is lost. Complicating this further is the fact that these conditions are unpredictable and subject to change given the current issues being faced as a result of climate change.

Unlike fossil fuels, RETs are site specific meaning that certain technologies can only be exploited in certain areas with the suitable conditions. In order to establish this onsite measurements are required over a long periods (minimum 1 year) combined with detailed modelling (IPCC 2011, Kanase-Patil *et al.* 2010, Nugent & Sovacool 2014).

Concerns have also been highlighted about the ability of RETs to generate sufficient levels of energy. Furthermore an issue that arises with the use of all RETs when used for decentralised energy provision is how the energy that is generated can be stored.

The intermittent nature of energy generation via RETs, in particular those which generate electricity, makes the ability to capture and store energy a crucial factor (Dubey *et al.* 2013). Generally electrical energy storage systems can be split into three groups, electrical, mechanical and chemical (Evans *et al.* 2012, Kousksou *et al.* 2014).

Electrical storage systems make use of capacitors and super-capacitors to store electrical energy in the form of electrostatic (Evans *et al.* 2012). Mechanical storage systems convert the electrical energy into potential energy. The two most common methods are compressed air and pumped hydro. For both methods the potential energy is utilised by the release of the compressed air or elevated water to run an electrical turbine (Evans *et al.* 2012, Kousksou *et al.* 2014, Rahman *et al.* 2012). It is worth nothing that pumped systems are net consumers of energy for example more energy is required to pump water to a higher elevation than is generated during its subsequent descent (Egré & Milewski 2002, Evans *et al.* 2012).

Both of these methods of energy storage are however considered impractical for use in a decentralised energy generation system in developing countries because they are all associated with considerably high capital costs and are only suitable for large scale projects (Evans *et al.* 2012, Kousksou *et al.* 2014, Nair & Garimella 2010, Yekini Suberu *et al.* 2014).

Batteries are electrochemical devices that are able to convert electrical energy into chemical energy for storage (charging) via electrochemical reactions and are capable of reversing the reaction (discharging) to generate electrical energy again without any noise or harmful emissions (Ibrahim *et al.* 2008, Kousksou *et al.* 2014, Yekini Suberu *et al.* 2014). These types are chemical storage systems are considered the best options to meet the energy storage needs of small to medium decentralised RET systems (Mohd *et al.* 2008, Nair & Garimella 2010).

In order for RETs to be as reliable as conventional centralised generation, energy storage is a critical factor (Kousksou *et al.* 2014, Nair & Garimella 2010, Yekini Suberu *et al.* 2014). It is essential to store the energy that is generated during off peak times and to ensure that a consistent uninterrupted supply can be maintained during peak times or when generation is interrupted (Dubey *et al.* 2013, Evans *et al.* 2012, Ibrahim *et al.* 2008, Kousksou *et al.* 2014, Yekini Suberu *et al.* 2014). The methods of energy storage are varied and in addition to adding an additional cost to any RET project could also affect the barriers to and impacts of a project.

Ehnberg & Bollen (2005) suggest however, that by combining different RETs some of these disadvantages can be overcome while holding onto many of the benefits they offer (Ehnberg & Bollen 2005).

2.1.2. Review Of RETs Suitable For Small Scale Decentralised Applications & Their Impacts:

In addition to the universal advantages and disadvantages of RETs discussed above, five RETs are explored in more detail to highlight some of the more specific and sometimes unique impacts that can be associated with their application which could be often overlooked.

Hydropower

Hydropower technology harvests the energy from water flowing from a higher level to a lower level. The water is used to drive a turbine, producing mechanical energy which can be turned into electricity by a generator (Arup 2004, El Bassam & Maegaard 2004, Nakata *et al.* 2011). The amount of electricity produced is directly proportional to the volume of water and the vertical difference. Therefore, the benefit of this technology is that a similar amount of energy can be generated from a small volume of water over a long distance or a larger amount of water over a shorter distance (Arup 2004).

The technology used to deliver hydropower is well established, reliable and has low maintenance costs, but is associated with high initial investment costs (Holm 2005, Kaygusuz 2012). It has been extensively used for large scale systems in the past but now the use of small scale systems are being expended as an alternative in regions where other options are not viable (Nakata *et al.* 2011). Comparison to other RETs used for small scale applications, the investment cost per kWh associated with small hydro projects are low at $1,150 per kW (IEA 2007).

The major advantage of hydropower projects are that once complete they can, under the right condition, provide a near constant supply of power as they are less affected by seasonal or daily intermittences as seen with other RETs. This is not to say that they are wholly impervious, as extreme conditions (floods, droughts) can affect generation.

There are three main types of hydropower systems, impoundment, diversion and pumped storage (El Bassam & Maegaard 2004, United States Department for Energy (DOE) 2014, Vilanova & Balestieri 2014).

Impoundment systems, which use dams to store water, are typically reserved for large scale projects and are associated with major adverse environmental impacts (Premalatha *et al.* 2014). Which include deforestation and loss of habitat, disruption of riparian organisms and fish stocks due to changes in river flows, as well as displacement of human populations (Breeze 2014, Erlewein 2013, Nakata *et al.* 2011, Premalatha *et al.* 2014). In some regions they can also lead to an increased incidence of waterborne diseases and there has even been evidence presented linking these projects with emission of large volume of the GHG methane from the manmade reservoirs (Giles 2006, Premalatha *et al.* 2014). There is however some debate as to the extent of these emissions. With some speculating that they are comparable to traditional fossil based energy sources (Lima *et al.* 2008) and others applying more conservative estimates and suggesting variation between regions (Bergier *et al.* 2014, Narvenkar *et al.* 2013).

Pumped systems work by using the energy generated during periods of low demand to pump water from a low to a high reservoir. This water can then be released when the demand grows to generate energy (El Bassam & Maegaard 2004, Evans *et al.* 2012, United States Department for Energy (DOE) 2014, Vilanova & Balestieri 2014). Unfortunately like impounded systems pumped hydropower requires large reservoirs of water. This can result in similar environmental impacts such as deforestation and loss of habitat. Unlike the use of dams where the impacts occur in the immediate area surrounding the water source, these impacts can be displaced away from the site of power generation with the water pumped over a distance. This may not have a significant effect upon the degree of the impacts it may even exacerbate them. It is worth noting that impoundment and pumped hydro projects can also offer some level of drought and flood resistance (Breeze 2014, Kumar & Katoch 2014, Premalatha *et al.* 2014).

Power generation by diversion, or run-of-river project are far more suited for small scale generation. A portion of a rivers flow is diverted away from the main channel using canals or penstocks to a turbine station and then the water is returned to the river (El Bassam & Maegaard 2004, United States Department for Energy (DOE) 2014).

These projects are the least disruptive, cheapest and easiest to implement of all hydro systems (Breeze 2014, Kumar & Katoch 2014). However, unlike their counter parts they do not store potential energy therefore require a constant water flow. If this is disrupted then production will affected and could temporarily cease (Breeze 2014, Nakata *et al.* 2011).

Although associated with similar environmental impacts as other hydropower projects, they are by comparison much smaller. Primarily due to the absence of any reservoir, but also due to the small size of the projects (Breeze 2014, Egré & Milewski 2002, Kucukali 2014, Kumar & Katoch 2014). They have fewer effect on the river flow and sediment movement which reduces downstream impacts, they also have little effect upon fish migration (Egré & Milewski 2002, Kumar & Katoch 2014).

All hydropower projects will require some level of infrastructure development. This will possible include the construction of access roads to enable the project development. If the target community of a small hydro project do not reside close to the point of generation the energy generated will need to be transmitted over the distance between them. This not only adds to the infrastructure impacts but also the costs of a project.

All of these methods can affect downstream water quality during and after construction, which can lead to adverse effects if the water is used for irrigation or drinking (Nakata *et al.* 2011).

Hydropower projects are very site specific, projects that requires the building of a dam or reservoir are also geographically and geologically constrained (Breeze 2014). This all means that the impacts of two projects will vary significantly and, although they can be generalised, the actual impact cannot been known until suitable sites are identified and evaluated.

The local available resource is a key consideration for hydropower schemes, as with many renewable technologies. Although the associated built elements are usually small for decentralised energy schemes, they can be costly and therefore the scale of the development must be in-line with the predicted energy requirement.

Solar Energy

Solar photovoltaic (PV) technologies commonly referred to as solar panels, enable electricity to be generated from solar radiation originating from the sun (Bast *et al.* 2011, Hernandez *et al.* 2014, Hiremath *et al.* 2009, Nakata *et al.* 2011, Varun *et al.* 2009). PV systems can be operated during winter and cloudy conditions but with significantly reduced output (Nakata *et al.* 2011). They require minimal maintenance, are silent, highly reliable and because of their modular nature are ideal for remote locations geographically positioned close to the equator such as Africa, India and Asia (Chauhan & Saini 2014, Dubey *et al.* 2013, Hiremath *et al.* 2009, Nakata *et al.* 2011, Varun *et al.* 2009). Despite this, comparison to other RETs used for decentralised applications, the investment costs per kWh associated with PV projects are the highest at $10,000 per kW (IEA 2007). Costs have however been dropping with increase research and development, and successful deployment (Kaygusuz 2012).

There are virtually no environmental hazards associated with the use of small scale PV systems. There are however various impacts during the manufacture and disposal of the PV cells that make up the panels which present the largest environmental problems (Fthenakis 2013, Nakata *et al.* 2011, Zhang *et al.* 2012).

Various hazardous materials are associated with the manufacture of PV cells. Although in small quantities, when compared to other industries they still pose significant environmental and occupational risks (Dubey *et al.* 2013, Fthenakis 2013, Hernandez *et al.* 2014). The key risks posed by these materials result from their toxicological properties and explosiveness (Dubey *et al.* 2013, Fthenakis 2013). If proper measures are taken the risks these materials pose can be reduced.

The majority of the components and materials in a PV cell (glass, aluminium, copper) are produced through well-established methods which are efficient. In contrast the production of silicon, which is the most common material used in PV cells to form the semiconductor which convert the solar radiation to electrical energy, is still in its infancy and is very energy intensive (Dubey *et al.* 2013, Nakata *et al.* 2011).

As the manufacture of PV systems is driven primarily by the use of electricity, the environmental impacts from this will vary depending upon the energy mix used (Dubey *et al.* 2013, Nugent & Sovacool 2014). Assuming that the energy mix is primarily fossil based resources the most significant impacts will be that which come from the release of additional anthropogenic GHGs.

Estimates for the levels of GHG released during the production and disposal of solar cells provide an average of 49.9 g CO_2e/kWh[2] (Nugent & Sovacool 2014). Nugent & Sovacool (2014) showed that 71.3% of the total GHG emission associated with the life cycle of PV modules resulted from material acquirement, processing and manufacture (Nugent & Sovacool 2014). However, given that 99.0% of PV materials are recyclable with the proper processing a large portion of these emissions could be offset (Dubey *et al.* 2013).

Unfortunately the recycling of PV is complex and not yet a widely accessible industrial pathway. (Dubey *et al.* 2013, Querini *et al.* 2012). This poses a problem especially if a module is used in remote areas where it could be difficult to recover, or in countries that lack the required recycling capabilities. These factors would make recycling difficult and expensive, especially if the panel would need to be exported to another region/country. It is far more likely that under these circumstances a module once decommissioned would be disposed of via incinerated or landfill.

Although incineration will recover some of the embodied energy it does not offset anywhere near the same level of GHGs as recycling (Dubey *et al.* 2013). Incineration can also result in a portion of the heavy metals that can be found in PV systems (lead, cadmium) being gasified and released into the atmosphere (Fthenakis 2013). During landfill scenarios it is also possible for these heavy metals to leach out and contaminate the surrounding soil and groundwater (Cyrs *et al.* 2014, Fthenakis 2013).

PV technologies offer great potential as a means of delivering modern energy services. It is worth highlighting that there are negative impacts associated with their manufacture and disposal. Many of which will always be experienced away from the site of use

[2] Volume of GHGs released per kWh of electricity generated (Nugent & Sovacool 2014, Ortegon *et al.* 2013)

(Dubey *et al.* 2013), except the global impact of GHGs. The use of these technologies will however likely offset these GHG emission through the avoidance of fossil fuels.

Wind Energy

Wind turbines produce electricity by capturing the energy from the wind through a turbine to drive a generator (Nakata *et al.* 2011, RenewableUK 2010). The generator is an important feature and typically one of three types (induction, synchronous and direct current) are used depending on the scale of the turbine. For small turbines typically direct current generators are used (Nakata *et al.* 2011).

There are two main types of wind turbine design, horizontal axis (HA) and vertical axis (VA) (see Figure 2.1). HA turbines are the most common (Nakata *et al.* 2011).

Figure 2.1: Examples of vertical axis (left) and horizontal axis (right) wind turbines

The advantage of VA over HA turbines is that they can take advantage of the wind from any direction, they do not have to reposition unlike like HA turbines. However they are unable to take advantage of higher wind velocity at higher elevations (Nakata *et al.* 2011).

Turbines can vary in size, from household systems up to larger community projects. The power generated from a wind turbine is proportional to the wind speed cubed and therefore minor changes in wind speed can result in large changes in output leading to an intermittent supply of energy (Nayar *et al.* 1991). Despite this, the suitability of small scale wind power projects for remote locations that do not have an electrical grid connection has been recognised (Leary *et al.* 2012). A possible barrier however are the relatively high investment costs per kWh generated ($3,500 per kWh) compared to other RETs used for small scale projects (IEA 2007).

Like PV systems the major environmental impacts of wind turbines comes from their manufacture and improper disposal (Guezuraga *et al.* 2012, Nugent & Sovacool 2014). Nugent & Sovacool (2014) showed that on average of the total GHG emissions associated with the life cycle of a wind turbine 71.5% could be attributed to material acquirement, processing and final manufacturing. Furthermore 24.0% could be attributed to site setup/construction (Nugent & Sovacool 2014). Nugent & Sovacool (2014) estimated that the 34.1g CO_2e could be attributed to each kWh of electricity generated over their lifecycle.

Steel, aluminium, copper, glass fibre, polyester, carbon fibre and epoxy are the main materials used in the manufacture of wind turbines (Cherrington *et al.* 2012, Querini *et al.* 2012). At their end-of-life (EOL) most parts of a wind turbine can be recycled, it has been estimated that 80.0% is recyclable so there is potential to recover some of the embodied energy and offset the GHG emissions (Cherrington *et al.* 2012, Ortegon *et al.* 2013, Querini *et al.* 2012). Estimates for the volume of total CO_2e that can be offset by recycling range from 3.2-59.4% with an average of 22.4% (Nugent & Sovacool 2014).

This estimate for the percent of recyclable material does not however include the foundations. Though it is worth considering that once installed the foundations may be reusable for the site of further installations. This would remove the need for and avoid the impacts (deforestation, GHG emissions etc.) associated with the installing of new foundations.

Unlike PV systems, wind turbines are less inconspicuous, and have been connected to several impacts experienced in the immediate area of their installation.

Deforestation and habitat loss in order to establish a suitable site for installation can occur especially for larger community scale projects (Saidur *et al.* 2011, Tabassum *et al.* 2014). Furthermore access roads may need to be built or improved to enable delivery of the components and site construction. Smaller household size projects may not incur these impact to the same degree but will not avoid them all together.

Some researchers have identified wind turbines as posing a risk to flying organisms, in particular bats and birds, as they can cause deaths when these animals collide with the turbine (Leung & Yang 2012, Saidur *et al.* 2011, Tabassum *et al.* 2014). However, the number of deaths that occur in this way are negligible compare to those that result from indirect impacts such as deforestation (Leung & Yang 2012, Saidur *et al.* 2011). Despite this the number of death are still much smaller than compared to other sources of energy generation. In addition more birds are killed by plane strikes and the risks posed by climate change to habitats destruction are a far greater threat (El Bassam & Maegaard 2004, Saidur *et al.* 2011).

There are also some studies that showed that after sometime birds have been observed to learn to avoid the turbines, and that a variety of factors can affect the risk of collision. Which beside turbine size and blade speed also includes weather conditions and lighting (Leung & Yang 2012, Saidur *et al.* 2011, Tabassum *et al.* 2014). Johnson *et al.* (2000) found that 93.8% of fatalities occurred as a result of factors related to weather conditions (Johnson *et al.* 2000). It is also worth noting that this particular impact will vary between regions and that the installation of a wind turbine does not automatically result in deaths.

Noise pollution during generation is another negative environmental impact that has been associated to wind turbines. It has been linked to sleep disturbance, psychological distress and possible damage to the vestibular system (Leung & Yang 2012, Tabassum *et al.* 2014). It is however often a subjective issue as it is relative to level of annoyance a residents has towards the turbine (Tabassum *et al.* 2014). Respondents who do not hear the noise or perceive the turbines as a benefit are less likely to be annoyed by them and therefore are at a reduced risk (Tabassum *et al.* 2014). There are two sources of noise from a turbine, mechanical and aerodynamic, both can be reduced during the design and construction stages (Leung & Yang 2012, Saidur *et al.* 2011, Tabassum *et al.* 2014).

Geothermal

Geothermal energy systems exploit the elevated temperatures found as you move deeper into the earth crust generated by continuous radionuclide decay to generate power from steam. After solar energy, geothermal is the most abundant natural energy resource on the planet (Bayer *et al.* 2013, Nakata *et al.* 2011).

There are a variety of different methods used to exploit this resource with four main ways for energy generation: dry steam power plants, single or double flash steam power plants and binary cycle power plants (Bayer *et al.* 2013, Nakata *et al.* 2011).

Geothermal power is generally associated with minimal environmental impacts compared to other RETs and is highly reliable, but has very high installation costs and thermal energy is not very effective when transferred over long distances (Bayer *et al.* 2013, DiPippo 2012b, Nakata *et al.* 2011).

Although there is the potential for some small impacts during their operation, the majority of the impacts come from site and infrastructure construction necessary for a projects setup.

Complete facilities comprise of several structures and auxiliary buildings and as geothermal power generation is site specific there may be very little option as to where a plant can be established (Bayer *et al.* 2013, DiPippo 2012b, Kaygusuz 2012). This may result in significant environmental damage and habitat loss. Notable there have been multiple cases where plants have caused the loss of hydrothermal manifestations such as hot springs and geysers (DiPippo 2012a, DiPippo 2012b, Keam *et al.* 2005)

There will also be additional damage from the need to construct access roads to enable construction and ongoing maintenance. Furthermore it is unlikely that the site of generation will be close to the site of use which will require the installation of transmission lines which can also result in addition damage and habitat loss (Bayer *et al.* 2013).

There are also potential geological hazards that arise from the establishment of these energy sources. These hazards include increased seismicity, sinkholes, landslides and slumps (Bayer *et al.* 2013, DiPippo 2012a, DiPippo 2012b, Pasvanoğlu *et al.* 2012). Not all of these impacts, if any, are experienced at all geothermal sites and the extent of which they are observed can also vary considerable (DiPippo 2012b). Nevertheless these impacts can lead to loss of land and specialist habitats due to flooding, damage to buildings and infrastructure (including the plant) as well altering the hydrological flow regime of an area.

These hazards often occur because of the reduced reservoir pressure after fluid removal, and are more common where the fluid reservoirs are under lithostatic pressure. The need to drill new wells every few years can also exacerbate conditions (Bayer *et al.* 2013, DiPippo 2012b, El Bassam & Maegaard 2004). Reinjection of waste fluids back into the wells to maintain reservoir pressure can mitigate some of these impacts, and although it does not guarantee their avoidance entirely it can reduce the risk posed (Bayer *et al.* 2013, DiPippo 2012b).

Geothermal plants can also lead to the release of various atmospheric pollutants, including H_2S and the GHGs CO_2 and CH_4 (Bayer *et al.* 2013, El Bassam & Maegaard 2004). Typically they are associated with the exhaust emission from transport and site construction, however these emissions in comparison to fugitive emissions, which are often underrated, are relatively small (Bayer *et al.* 2013). Small trace amounts of Hg, NH_3, Rd, As and B have also been reported in emissions which can lead to contamination of soil and water if they are leached by rain as well as detrimental effects on the local biodiversity (Bayer *et al.* 2013). These emission are still very low in comparison to fossil fuel power plants and the impacts can be controlled by re-injecting waste gases or fluids back into geothermal well (El Bassam & Maegaard 2004).

The installation and operation of geothermal plants can often require considerable amounts of water, which can put it in direct competition with other activities (arable farming) as well as local communities (Bayer *et al.* 2013). This can lead to significant impacts if the plant is in a region with already scarce water resources.

Some of the impacts of geothermal power generation are temporary and are only experience during site establishment, some are however more long term and can lead to prolong effects. Although mostly localised to the area surrounding the plant the impacts can contribute to much wider factors, such as global warming.

The limited number of suitable sites and the variation in efficiency that is observed between sites depending on the geological conditions are major restrictions which limit the uptake and constrain the use of geothermal energy generation particularly as a decentralised energy source (Bayer *et al.* 2013, Nakata *et al.* 2011).

Bioenergy

Bioenergy refers to renewable energy resources made available from organic matter, such as virgin wood, energy crops, agricultural residues, food waste and industrial waste (BiomassEnergyCentre 2012, Hiremath *et al.* 2009). Bioenergy is the extraction of energy from biomass. One of the advantages of this fuel is that it is often a waste or by-product from a process such as farming or forestry. They are also often perceived as carbon neutral as the carbon they release is only that which has been sequestered from the atmosphere recently, therefore there is no net addition to atmospheric carbon concentrations (Borges Neto *et al.* 2010).

Biofuels are produced from processing biomass into a more convenient form, principally to increase energy density. They can roughly be split into three main categories; solid biomass, liquid biofuel or gaseous fuel (biogas) (Hiremath *et al.* 2009, Nakata *et al.* 2011, Popp *et al.* 2014).

Heat and electricity can be generated via the direct combustion or gasification of solid biomass (Abbasi & Abbasi 2010). Although a renewable source of energy the direct burning of biomass has been linked with various negative human health impacts resulting from local air pollution (Epstein *et al.* 2013, IEA 2007).

Biogas is obtained through the anaerobic digestion of organic matter which produced a mixture of CO_2 and CH_4 (Abbasi & Abbasi 2010, Nakata *et al.* 2011). The latter of which can be combusted. This process has however experienced various operational problems and low efficiency when using plant biomass as a feedstock (Abbasi & Abbasi 2010). There is also the danger that if the CH_4 is accidently released or leaks it will have greater impact as it GWP it over 80 greater than that of CO_2 (IPCC 2013).

Liquid biofuels in the form of ethanol or diesel can be produced through thermal and/or chemical processing of biomass. Esterification is one of the most well know and widely used chemical processes (Nakata *et al.* 2011). These processes also consume substantial amounts of energy during the processing of the feedstock which can reduce their offsetting effect on GHGs with some studies suggesting that they actually result in more GHG emission than they supposedly avoid (Abbasi & Abbasi 2010).

Due to the nature of biomass projects they are less practical for individual household and are more suited for medium to large projects. And despite their positive environmental image they have been associated with a range of detrimental impacts.

It is production of feedstock that presents the greatest challenges, not just through being able produce sufficient amount to meet demand but also the environmental challenges it poses. The major impacts linked to the feedstock include loss of land and land use change, air pollution, GHG emissions, reduced soil quality, reduced water quality and availability, plus loss of biodiversity (Harvey & Pilgrim 2011, Meyer & Priess 2014, Miyake *et al.* 2012, Popp *et al.* 2014).

Competition for land also stems from the space needed to install the required equipment to carry out feedstock processing as well as storage of the final fuel product. This can result in deforestation, habitat loss and loss of productive land. Clearing land also leads to the release of additional GHGs, CO_2 in particular as the organic matter breaks down. Change in land use has been linked to rising food prices as agricultural land is used to grow energy crops as feedstock for liquid biofuel production (Abbasi & Abbasi 2010, Escobar *et al.* 2008, Popp *et al.* 2014).

The use of synthetics fertilisers to boost feedstock production can lead to significant negative environmental impacts. The fertilisers contain the GHG N_2O which can be released into the atmosphere leading to localised air pollution, acidification and contribute to the more widespread impacts of climate change and stratospheric ozone depletion (Abbasi & Abbasi 2010).

This fertiliser can also find its way into the local water sources polluting them and resulting in eutrophication. Water is another resource that is put under increasing pressure as large volumes are required for feedstock production (Abbasi & Abbasi 2010).

The carbon neutral appearance of biofuels can make them a very attractive means of energy provision. However once all the challenges and environmental issues associated with them are taken into consideration they may not offer the best solution for delivering modern energy services.

2.1.3. The Future Of LCTs

The use of modern renewable energy sources (wind, solar, geothermal, marine and modern biomass and hydro) is expected to increase so that by 2035 they will account for approximately 14% of the global primary energy usage (IEA 2011). The increase does not mean an even uptake across the range of individual renewables and the level of penetration each source achieves also varies considerably from region to region (IEA 2011).

However there are a range of barriers obstructing the adoption of RETs, which vary depending on the local conditions, from country to country as well as the technologies being employed. These include, but are not limited to, a lack of adequate infrastructure, technical skill, existing knowledge on the management, operation and regulation of RETs and substantial investment costs, all of which can hinder the development and uptake of RET projects (de Jager & Rathmann 2008, Del Río 2007, Dinesh Babu & Michaelowa 2003, Mitchell *et al.* 2011, Nautiyal & Varun 2012, Painuly 2001, Reddy & Painuly 2004).

Further work and investment is needed to increase the rate at which RETs are employed in order to move away from the current state of fossil fuel dependency, particularly in developing countries where their inclusion in the energy mix can help improve energy security while facilitating sustainable development (Dincer 2000, IPCC 2011).

2.2. Developing Countries & Modern Energy Services

Approximately 40% of the world's population (~3 billion people) are living without access to any modern energy service and/or are solely reliant upon the traditional use of biomass for cooking (IEA *et al.* 2010, UN-AGECC 2010, UNDP 2010c). According to the International Energy Agency (IEA), nearly all of these people reside within developing countries, and are mostly in rural or isolated areas (IEA *et al.* 2010).

Achieving universal modern energy access is a key objective in many developing countries as a means of supporting economic and social development (Gurung *et al.* 2011, Silva Herran & Nakata 2012). A clear correlation has been shown to exist between living standards and energy consumption (AusAID 2000, Demirbas & Demirbas 2007, DFID 2002a)

As previously highlighted, the vast majority of the growth in energy demand is going to be in developing countries. There is an increasing drive to do this with LCTs to avoid many of the socioeconomic and environmental impacts due to the use of more conventional fossil fuel based energy resources.

2.2.1. Current Energy Services

In most developing countries household energy needs are principally met through the use of traditional biomass fuels such as wood, and dung (UNDP 2005a). This is often due to low income and lack of accessible modern energy sources. These fuels represent the bottom rung of the energy ladder (UNDP 2005a) and have been linked to numerous local and global environmental problems including deforestation, soil degradation and climate change (Giannini Pereira *et al.* 2011, Reddy & Srinivas 2009, UNDP 2005a).

The use of these traditional fuels is associated with high levels of indoor air pollution (Bruce *et al.* 2011, IEA *et al.* 2010). Exposure to particulate matter mainly from cooking and heating with these fuels causes about 2.5 million deaths each year in developing countries (Bhide & Monroy 2011, Howells *et al.* 2005). Indeed, there are more premature deaths each year from household air pollution than from either malaria or tuberculosis (IEA *et al.* 2010). In addition to these premature deaths indoor air pollution has been estimated to result in the annual loss of 1.6-2.0 billion work days globally (Bhide & Monroy 2011).

Many developing countries have been making progress toward universal energy provision through various policies promoting national electrification (IEA *et al.* 2010).

According to the IEA, by 2015 the electrification rates of developing countries will be around 75.0%. However, the individual rates per country vary considerably (Chaurey *et al.* 2004, IEA *et al.* 2010). Having access to electricity does not automatically guarantee that the target users can make use of it, particularly if they are unable to pay for it or for the appliances needed to deliver the desired services (Nussbaumer *et al.* 2012, Winkler *et al.* 2011). Affordability is a key factor that determines the extent to which any energy source can be used. In addition, reliability is another key factor.

The UN estimates that on top of the 1.5 billion people living without any access to electricity, an additional 1 billion have access only in name as the supply is unreliable (UN-AGECC 2010). These people are unable to make full use of the social and economic benefits electricity offers as they are still reliant on the use of traditional energy services to fulfil their energy requirements, and by extension the environmental benefits are also not being gained.

2.2.2. The Need For Modern Energy Access In Developing Countries

The general benefits modern energy access can offer have already been presented in a previous section of this chapter. There are, however, factors that drive the need for modern energy access in developing countries specifically, some of which relate to overcoming issues highlighted previously, such as reliability, and health concerns. Others include the need to meet the growing energy demands of an increasing population, to overcome the threat energy poverty poses to sustainable development and to drive economic and social development as a whole.

The Necessity Of Modern Energy Services Due To Population Increases

According to the United Nations (UN), the global population has more than trebled in the past 50 years and is set to increase by a further 3 billion over the next 65 years (UNPD 2010). This increase in population is increasing demand upon global resources. Concerns are being raised regarding future energy and food security as nations may be unable to meet the basic requirements of their citizens (Hanjra & Qureshi 2010, Khan & Hanjra 2009, Xia 2003).

The vast majority of this population increase is expected to be in developing countries (UNPD 2010, Xia 2003). In particular the population of India is expected to increase by almost 500 million people by 2065 (based on 2010 figures) (UNPD 2010). This not only represents a population increase of 38.0% in India, but will mean the nation as a whole will account for almost 18.0% of the world’s total population (UNPD 2010).

In developing counties, increases in population and development go hand in hand, that is development can lead to population growth through improved living standards, and population increase, can itself act as a stimulus to drive development and thus energy demand. As a result, the majority of future global energy demand is expected to be in developing countries (BP-PLC 2011, UN-AGECC 2010, UNDP 2005a, Xia 2003). They are also where the most investment is needed in order to meet future primary energy needs. According to the IEA, India alone needs to invest $1.7 trillion in order to meet its future primary energy needs (IEA 2009). Such high associated cost can often make the provision of universal energy a significant challenge in these countries.

How rapidly developing countries such as India will meet their future energy demands in a sustainable manner is a growing concern as the global community continues to look for ways of alleviating the impacts faced by climate change, which has resulted from the release of anthropogenic greenhouse gases (IPCC 2008).

Energy Poverty & Development

Energy poverty in many developing countries poses a real threat to future development. It is caused by a combination of factors including lack of income and high energy costs as well as a lack of physical access to certain types of energy (Pachauri & Spreng 2011).

People are considered to be in energy poverty when they have inadequate and unreliable access to modern energy services and are still having to rely upon traditional biomass (IEA 2013, UN-AGECC 2010). These are the people whose energy access does not fulfil all of the criteria of 'basic human needs' as described by the UN-AGECC (see Figure 1.1).

However using this definition means that people can be classified as not being 'energy poor' but still have insufficient energy access to meet the minimum requirements (levels 1 and 2) described by the UN-AGECC.

People who are energy poor are also often income poor which leaves them financially unable to switch to more efficient, cleaner fuels (Balachandra 2011a). At the same time the impacts of having no option but to use traditional fuel (adverse health effect, and limiting of women's activities) can reduce the opportunities for income generation trapping these household in poverty (Bruce *et al.* 2011).

Just as an individual can be energy poor so can a nation where it is restricted by the access it has to financial and energy resources which ultimately prevents it from building adequate infrastructure that would enable connectivity to modern energy carriers (Balachandra 2011a). High fuel import costs also have an effect on the macroeconomics of a country as it often means funds are diverted away from other projects (Andrews 2005)

Violent conflict, civil wars and state failures have all stemmed from poverty and inequality. Extreme poverty in a country only further undermines national security and stability (UNDP 2010a). Countries experience higher rates of economic growth and poverty reduction when levels of inequality are low or falling, compared to those where inequality levels are rising or high (UNDP 2010a).

The Millennium Development Goals & Energy Access

Energy access has the power to have a profound impact upon various aspects of human development, from reducing poverty, improving gender equality, health, food security and climate change (UNDP 2010c). The best example of how energy access can positively affect the lives of people living in developing countries is through the impact it has on achieving the millennium development goals.

In September 2000 leaders from the member states of the United Nations (UN) signed the Millennium Declaration outlining eight goals, universally referred to as the Millennium Development Goals (MDG), aimed at encouraging development by improving social and economic conditions in the world's poorest countries (IEA *et al.* 2010, UN 2010, UNDP 2005b, UNDP 2010a, UNDP 2010b). The MDG not only outlined a set of target for developing counties, but also acknowledges the contribution developed countries can make through debt relief, fair trade and technology transfer which will significantly support their successful completion (Haines & Cassels 2004).

Specific goals include combating extreme poverty and hunger, reducing infant mortality and combating diseases such as HIV/AIDs and malaria. The target date for meeting these goals was set as 2015 (UN 2010, UNDP 2010a, UNDP 2010d), however despite significant progress having been made in some regions toward achieving these goals, recent reports published by the UN Development Programme (UNDP) suggest that many of the targets and goals are likely to be missed in most regions unless additional corrective action is taken immediately (UN 2010, UNDP 2010a, UNDP 2010d, UNDP 2014). The UN has attributed some of these shortfalls to be a result of the global financial and economic slowdown experienced in 2008, and the exacerbating effects of food and energy security issues. In some cases these impacts may have even eroded some of the previous progress (UN 2010, UNDP 2010a, UNDP 2010b).

This explanation may lead to other underlying issues hampering the fulfilment of the MDG being overlooked. A UNDP report published in 2005, three years prior to the economic downturn, had already noted setbacks, stating that *"many regions are off-track to meet the goals"* (UNDP 2005b), suggesting that failures to meet targets and goals may have been due to other factors.

The same report notes that the provision of energy services as an important requirement in fulfilling all of the MDG (Kaygusuz 2012, UNDP 2005b). There is however no specific MDG relating to the provision of modern energy services, or any specific targets or indicators within the existing goals that allow for the monitoring of access (IEA *et al.* 2010, Ogola *et al.* 2011, UNDP 2005b).

The importance of delivering energy services as being a prerequisite for the fulfilment of the MDG was recognised at the 2002 World Summit for Sustainable Development (WSSD) in Johannesburg (Pachauri *et al.* 2004, UNDP 2005a, UNDP 2005b, UNDP 2010d, WEHAB 2002) and has since been repeatedly highlighted in several UNDP reports (UNDP 2005a, UNDP 2005b, UNDP 2010b, UNDP 2010c, UNDP 2010d) as well as by other observers including the United Kingdom's Department for International Development (DFID) (DFID 2002a) and the International Energy Agency (IEA) (IEA *et al.* 2010).

A recent report from the UN identified inadequate energy systems as a threat to realising the MDG by 2015 (UN-AGECC 2010). The report also responded to calls for a new goal targeting universal energy access by outlining two new aims (UN-AGECC 2010).

1) Ensure universal access to modern energy services by 2030

2) Reduce global energy intensity by 40% by 2030.

These two targets aim to provide a platform by which movement towards sustainable universal energy access can be achieved. However, there has not been any international agreement or declaration from the UN members committing to achieving these goals as seen with the MDG in September 2000. Despite this, the report emphasises the significances of delivering these two goals as being key in accomplishing the MDG

(UN-AGECC 2010). The target date for their fulfilment of these targets, however, is fifteen years after the MDG deadline.

In a report by the UNDP, the importance of investing in activities across all the MDGs was highlighted as the relationships between different goals means that progress in one supports progress in others (UNDP 2010e). Attempting to tackle one goal at a time will ultimately end in failure to achieve all the goals. For the greatest impact therefore equal attention needs to be given to all the goals (UNDP 2010e).

Energy provision therefore has an even more vital position in the fulfilment of the MDGs as investing in this one area directly or indirectly contributes to the fulfilment of all the individual goals simultaneously.

Like the driving factors behind the requirement for energy, it is the services that energy provides, not the energy itself that is helping fulfil these goals.

A further threat to the achievement of MDG is climate change, the impacts of which are expected to be felt most severely in the countries that are already struggling to achieve there MDGs (UNDP 2010b). The impacts of climate change will put significant pressure on what are already fragile economies, and divert the limited resources available away from investment in the MDG project (UNDP 2010b).

2.2.3. RETs & Developing Countries

The demand in developing countries for alternative energy sources, such as renewables, over the next twenty years is substantially lower than the demand for fossil fuels (OPEC 2011). This can be attributed to a range of socioeconomic barriers linked to the uptake of the technologies used to deliver these energy sources.

However, the expanded use of alternative renewable energy sources by developing countries in order to meet their energy demands is a more assured way by which they can continue to facilitate development and circumvent many of the environmental and social problems associated with the use of fossil fuels (Holm 2005).

Furthermore by utilising renewable energy technologies many developing countries will be helping to protect their own future energy security as well as avoiding many of the risk associated with being a major importer of fossil fuels, such as price volatility which can lead to regional destabilisation and increasing national debt as a result of increasing fuel expenditure (Holm 2005, Ölz *et al.* 2007).

2.2.4. RETs & Rural Energy Provision

As already highlighted the vast majority of people living without any modern energy access, or who are reliant upon biomass for cooking are found in the rural and isolated areas of developing countries (IEA *et al.* 2010). These communities are often unable to meet all of their energy requirement's (Johnson & Bryden 2012). Further complicating this situation is that the population of many developing countries are spread out over large areas with long distances between small communities (Mishnaevsky Jr *et al.* 2011). This can often mean that the provision of modern energy via traditional centralised means is not just impractical but also expensive (Demirbas & Demirbas 2007).

The low population density of these communities typically also means low levels of energy demand (Kaygusuz 2011, Mishnaevsky Jr *et al.* 2011). This can make energy provision via centralised generation an uneconomic venture for power providers who have to invest in the infrastructure necessary for its delivery (Kaygusuz 2011). These costs could be passed onto the end users and as a consequence could restrict how accessible the energy is as it may become unaffordable.

In addition, the UNDP believes that the vast majority of the world's poor would never be reached by centralised energy systems in their own lifetimes if things are left as they are (UNDP 2010c).

Decentralised energy provision is one option for meeting the modern energy requirements of these communities in a reliable, affordable and sustainable way (Hiremath *et al.* 2009, Silva Herran & Nakata 2012, UNDP 2010c). It also avoids many of the negative impacts and costs associated with centralised generation, in particular those incurred as a result of generation, transmission and distribution (Chakrabarti & Chakrabarti 2002, Hiremath *et al.* 2009, Kamalapur & Udaykumar 2011, Thiam 2010)

The use of RETs as a source of decentralised energy is proving to not only be a viable and efficient option for rural energy provision but also a sustainable one that supports both economic and social development in these rural areas (Bast *et al.* 2011, Mahapatra & Dasappa 2012).

The modularity associated with decentralised generation systems also offers the end users a number of benefits. 1) a degree of energy independence, 2) opportunities for local control to improve security of supply, 3) equal or better power quality, 4) a cleaner environment, 5) can lead to localised employment opportunities (Hiremath *et al.* 2009, Kamalapur & Udaykumar 2011).

Research has also found that small decentralised RETs projects are cost-competitive with grid extension especially for areas with a low number of households and low levels of demand; furthermore they even have the potential to displace other established decentralised methods of energy generation, in particular the use of diesel generators (IEA *et al.* 2010, IPCC 2011, Khanh Q 2007).

Many development strategies treat energy access only within the context of a large scale infrastructure project (UNDP 2005a), Small decentralised energy projects, if correctly designed and implemented can facilitate economic and social development while avoiding many negative impacts of the alternatives, particularly in rural areas (Demirbas & Demirbas 2007).

2.2.5. Barriers To The Adoption Of RETs

There are a variety of barriers obstructing the adoption of RETs, which have been widely identified in the literature. These barriers are not all universal; some are specific to a particular region or country, or to the individual technology. The barriers can be categorised into distinct fields; infrastructure and technology, institutional and regulatory, and social and economic.

Infrastructure & Technology

A lack of adequate infrastructure, be it access roads, grid connectivity or just the availability of land, can hinder the development and uptake of RET projects (Mitchell *et al.* 2011, Painuly 2001) . The lack of infrastructure in rural areas in particular, can deter investors and developers because of the difficulties presented, often leaving these areas isolated from sustainable development (Nautiyal & Varun 2012).

In many developing countries substantial investment is required in order to improve the infrastructure to allow projects to be completed; which in turn increases the overall project costs which may be passed onto the consumer (Mitchell *et al.* 2011, Painuly 2001, Rady 1992). The Clean development mechanism (CDM) could provide the means by which these costs could be reduced. The CDM was introduced under the Kyoto Protocol and allows governments, private companies and investors from developed countries to earn 'certified emission reduction' (CER) credits by contributing to or implementing emission reducing projects in developing countries These CER credits can be sold or used to meet their Kyoto compliance targets (Akella *et al.* 2009, AusAID 2000, Kaygusuz 2012, UNFCCC 2014).

A lack of technical knowledge and skilled personnel for setting up and operating these technologies in a country can also lead to problems in attracting investors as well as assuring the long term success of a project (Del Río 2007, Painuly 2001). Adequate levels of training and skill development needs to be made available within a host country to ensure some level of autonomy, which will help ensure long term success and viability.

In some countries the lack of technical experience in dealing with RETs can result in a lack of adequate standards and codes for regulating their set up and operation (Painuly 2001). This can lead to performance issues as the products' quality can vary which can directly affect the perception and penetration of these technologies (Painuly 2001).

Institutional & Regulatory

Institutional and regulatory barriers often arise from a lack of knowledge and experience in the use and application of RETs by policy makers (Dinesh Babu & Michaelowa 2003, Dombi *et al.* 2014, Mitchell *et al.* 2011). This knowledge deficit can result in poorly designed policies can lead to improper implementation of RETs. The IPCC identified that a lack of knowledge in existing policy options means that some policymakers are not making use of the experiences of others when trying to design and implement their own RET policies. By not using this information they are overlooking how these policies worked and were implemented, factors that contributed to their success or failure, as well as the costs associated and the difficulties and benefits experienced as a result of their enactment and application (Mitchell *et al.* 2011).

In addition it was noted that a lack of information being reported on how effective policies are once implemented can hamper the design of new policies as well as the natural improvement of existing one (Mitchell *et al.* 2011). Failed policies can lead to a lack of confidence in those introducing them as well as the technologies they are design to promote (Painuly 2001). Increased uncertainties and a lack of confidence can contribute to increased project costs (Mitchell *et al.* 2011, Painuly 2001). It is therefore vital that policymakers communicate with the relevant stakeholders and clearly outline the benefits as well as any potential issues, this will help reduce policy opposition (Mitchell *et al.* 2011)

Other regulatory barriers arise from the fact that many countries lack the institutions and framework for dealing with RETs systems (de Jager & Rathmann 2008, Dombi *et al.* 2014, Moomow *et al.* 2011, Painuly 2001, Reddy & Painuly 2004). In many cases the regulations are designed on the assumption that the energy systems are large and centralised and therefore do not make the introduction of new, smaller scale systems easy (Moomow *et al.* 2011).

Economic & Social

Many of the social barriers are centred on acceptance of the technology or the services they offer (Moomow *et al.* 2011, Painuly 2001). These barriers may stem from concerns surrounding the impacts on the local environment, economy, as well as competition for local water and land resources. These concerns often result from a lack of knowledge and information of the benefits RETs can offer (Del Río 2007, Dinesh Babu & Michaelowa 2003, Dombi *et al.* 2014, Moomow *et al.* 2011, Reddy & Painuly 2004). Reddy & Painuly (2004) identified that the use of RETs is often perceived to be associated with some level of discomfort or sacrifice, in comparison to the use of conventional technologies, rather than offering an equivalent if not superior energy resource (Reddy & Painuly 2004). Acceptance is a key requirement in order to maintain market viability and ultimately enable the scaling up of RET projects. If the target communities are hostile towards the introduction of new RETs, the likelihood of their success is reduced (Cohen *et al.* 2014, Karytsas & Theodoropoulou 2014, Moomow *et al.* 2011, Painuly 2001).

In many cases overcoming these barriers can be achieved by establishing dedicated lines of communication between the planners and stakeholders from an early stage of planning (Moomow *et al.* 2011). By incorporating public participation into planning decisions and by educating the target populations of the long and short term benefits of using such technologies for energy generation, their acceptance and successful implementation should greatly improve.

Education programmes alongside the introduction of RETs not only help improve the public perception of the technologies but also provides training and experience to maintenance personnel who will maintain the equipment after installation (Bhide & Monroy 2011). A lack of sufficient power has also been highlighted as a problem, which is often a result of increased demand seen in newly connected communities who energy requirements increase after experiencing the services offered (AusAID 2000).

Planning of RETs projects should therefore take into account not just the basic energy requirements but the potential increase in order to be successful.

The high costs associated with the installation and maintenance of many RETs can often restrict access to them as they become an unaffordable solution for energy provision for poorer communities (Dombi *et al.* 2014, Painuly 2001, Reddy & Painuly 2004). However many policymakers may not recognise the true value of RETs in relation to the current energy market despite the high initial capital costs (AusAID 2000, Del Río 2007, Dinesh Babu & Michaelowa 2003, Mitchell *et al.* 2011, Painuly 2001, Reddy & Painuly 2004). In many cases only when the social benefits of using these technologies translate into clear public support will investments from governments or private stakeholders be risked (Del Río 2007, Rady 1992).

The additional costs that result from any need to improve infrastructure to enable the implementation of RETs can also be passed onto the consumer as mentioned earlier which can lead to problems of uptake when the costs start to exceed those in comparison to more conventional means of energy provision (Mitchell *et al.* 2011, Painuly 2001).

Financial institutions and private investors are also often reluctant to provide funding for small scale projects that are associated with such risks (Del Río 2007, Painuly 2001). In some cases institutions lack any form of strategy on how to fund these types of projects which makes accessing adequate and affordable capital harder (Del Río 2007, Dinesh Babu & Michaelowa 2003, Painuly 2001, Reddy & Painuly 2004). This can therefore often make it almost impossible for people with low income or small firms to invest in these types of technologies (Reddy & Painuly 2004)

2.3. India & Modern Energy Access

India is widely recognised a rapidly developing country with a rapidly growing population (IEA 2012). Its GDP has grown 7.5% in the last ten years making it the ninth largest economy in the world (MSPI 2013). It population is estimated to overtake China as the world’s most populated country by 2025, with its own population expected to continue to increase until it peaks at just over 1.7 billion by 2060 (UNPD 2010).

According to India’s 2001 census 72.2% of its population lives in it rural areas (ORGC India 2001d). This rural population is not only home to the vast majority of the country’s poorest people, but the majority is also considered to be living in energy poverty, having to rely on traditional more affordable biomass to meet their household energy needs (Balachandra 2011a, IEA 2012, Pachauri *et al.* 2004, Urban *et al.* 2009).

The impact that energy poverty is having upon the country's economic development has prompted the Indian government to take action in providing affordable energy access to the entire population (IEA 2012, Urban *et al.* 2009). RETs are more and more being seen as a crucial element in the countries energy policies, in particular in meeting the energy needs of those in the countries rural and remote communities while also aiding the governments other policy objectives of future energy security and climate change mitigation (IEA 2012, Kumar *et al.* 2010)

2.3.1. Current Energy Situation

India's largest energy resources are coal, biomass and oil, which constitutes 42.0% 25.0%[3] and 24.0% of the nation's energy mix respectively (IEA 2012). The largest sectoral energy demand comes from the power sector which accounts for 38.0% of the nation's total primary energy demand. This demand from the power sector is only forecast to grow over the next two decades (IEA 2012).

As India's energy demand has grown and its indigenous resources have failed to keep pace so has its dependency on imported fuels, which increased from 11.0% in 1990 to 35.0% by 2009 (Chaturvedi & Samdarshi 2011, IEA 2012). An increase in CO_2 emissions has also been seen that now places it as the third largest emitter in the world (IEA 2012).

Despite this growth in the energy sector there are still an estimated 600 million people in India who do not have access to electricity on a regular and secure basis (Giannini Pereira *et al.* 2011). India's electricity sector consistently has peak shortages over 10.0% (IEA 2012, Shukla *et al.* 2009) yet also over-produced during off-peak times largely due to government subsidies (Chikkatur *et al.* 2007). This supply/demand gap is expected to increase further if action isn't taken swiftly (IEA 2012). The problems with India's electricity sector where highlighted when in 2012 black outs left 620 million people (approximately 9% of the world population) without electricity for two days.

The installed capacity for power generation is not evenly distributed across the country. The majority of India's installed capacity is found in the countries western states (IEA 2012). Different states have their own unique energy mix, which reflects their

[3] Some estimates put this higher at 32.0% of national primary energy consumption (Bhide & Monroy 2011)

infrastructure, resource availability and policy initiatives (IEA 2012). The gap between supply and demand is exacerbated by this regional concentration of generation capacity, and the variety in energy mixes can lead to seasonal variation in supply and demand peaks (IEA 2012). A well-integrated national grid is essential to surmount these factors as they contribute significantly towards the continued uneven economic development currently seen across the country (IEA 2012)

2.3.2. Future Energy Demand

India's energy consumption is growing at a rate of 4.0% per annum (Reddy *et al.* 2006), its per-capita energy consumption is however still very low at 0.58 toe[4]/capita. This is below the world average of 1.8 toe/capita and is even low compared to other developing nations (China 1.7 toe/capita, Africa 0.67 toe/capita) (IEA 2012). This low per-capita indicates that India's is a long way from capacity (IEA 2012)

Economic growth is needed to facilitate sustainable development in India, this will require a substantial increase in the quantity and quality of energy currently being used (Chaturvedi & Samdarshi 2011, Kumar *et al.* 2010, Parikh & Parikh 2011, Ravindranath *et al.* 2011). At present coal is expected to remain the primary means of energy generation this however raises concern surrounding increase CO_2 emission and the exacerbated impacts of climate change (Garg & Shukla 2009).

India's fast growing economy and rapidly increasing population raises concerns about the nation's future energy security, which at present is underpinned by an abundant domestic coal supply (Chaturvedi & Samdarshi 2011, Garg & Shukla 2009). This coal however is of low quality so is an inefficient source and highly polluting and also results in very high CO_2 emissions (Bhide & Monroy 2011, Pode 2010)

A case has been put forward for the expanded use of RETs as a means of moving away from a fossil fuel based economy and addressing the issues of climate change while still assuring national energy security and delivering modern energy services to facilitate development (Pode 2010). India's has an abundance of untapped renewable resources including a long coast line with high wind velocities, numerous rivers suitable for hydropower projects, a significant annual production of biomass and also receives among the highest solar radiation in the world (Singh & Parida 2013). The government is therefore keen to increase the share renewable energy makes to its installed power generation capacity to supplement current means of energy generation in order to meet

[4] Tonnes of oil equivalent

the basic energy needs of the country population, especially those in rural and remote areas (Hiremath *et al.* 2009, MSPI 2013).

2.3.3. Rural Energy Demand

A significant barrier to development in India is the lack of access rural and remote communities have to modern energy resources, in particular electricity (Castellanos *et al.* 2015, Kanase-Patil *et al.* 2010). Traditional fuels are still used to fulfil between 80.0% - 90.0% of all rural energy requirements (Bhide & Monroy 2011).

Electricity as one of the cleanest energy transfer options available forms the basis for most development projects irrespective of its origin (Kanase-Patil *et al.* 2010). Despite figures indicating that 74.0% of India's villages have been electrified only 54.9% of households actually had electricity access (Balachandra 2011a). A village is considered to be 'electrified' if at least 10.0% of households are connected (Hiremath *et al.* 2009, MOPI 2006a).

According to Balachandra (2011a) only 55.0% of India's rural households actually use electricity for lighting, 44.0% still make use of kerosene which is noted as being grossly inefficient and increasingly expensive (Balachandra 2011a, Balachandra 2011b, Hiremath *et al.* 2009). In the poorest rural households the situation is worse with 61.0% using kerosene for household lighting (Balachandra 2011a).

Estimates have shown that on average each rural household requires five hours of lighting per day with electrified rural households consuming approximately 470 kWh of electricity per year, with on average 165 kWh per year being exclusively for lighting (Balachandra 2011a).

The lack of energy access in India's rural communities is not limited to electricity but also fuels for household cooking. Energy used for household cooking often accounts for almost 90.0% of the total household energy demand (Bhattacharyya 2006). Estimates suggest that between 85.2% and 89.8% of India's rural population does not have access to any modern energy fuels for household cooking (Balachandra 2011a, Bhide & Monroy 2011). In many rural communities biomass has traditionally been the only fuel available, 84.0% of rural households using solid biomass fuels for cooking (Balachandra 2011a, Giannini Pereira *et al.* 2011, Kaygusuz 2011, Parikh & Parikh 2011). These are often used in conjunction with traditional stoves which are noted as not being very efficient (Balachandra 2011a).

In addition to solid biomass fuels, modern energy carries such as LPG, kerosene, biogas and electricity were only being used by 10.3% of rural households as primary fuels for cooking (Balachandra 2011a). LPG is used by only 8.6% of households, kerosene by 1.8%, biogas by 0.3% and electricity by 0.1% (Balachandra 2011a).

Previous studies have described how the majority of rural household have to make use of more than one fuel to meet their energy requirements for household cooking (Balachandra 2011a, Kaygusuz 2011). This could be a direct result of inadequate or unaffordable energy resource, so users retain a mixture of fuels to reduce the costs or risks associated to any one resource while maintaining a consistent supply (Kaygusuz 2011).

Unlike the many initiatives and programs that the Indian government has implemented to help increase universal electricity access, particularly in rural areas, there are very few that aim to tackle the issues of modern energy sources for household cooking (Balachandra 2011a, Balachandra 2011b, Rao *et al.* 2009).

Previous work has shown that rural households with higher rates of income consume more energy and are more likely to use modern energy resources to meet their energy needs (Balachandra 2011a, Bhide & Monroy 2011, Rao & Reddy 2007, Reddy & Srinivas 2009). For example Balachandra (2011) found that LPG for household cooking was being used by 33.0% of high income rural households but only 0.7% of low income households, whereas biomass was being used by 92.9% of low income households and only 54.1% of high income households (Balachandra 2011a). Further to this only these top income household showed a preference toward switching to modern energy forms over more traditional solid fuels (Bhide & Monroy 2011).

Low population density and purchasing power as well as the remoteness of many of India’s rural communities all contribute to making it more expensive to supply modern energy services than urban areas (Bhide & Monroy 2011). The status of India’s rural energy access as describe is however due to several failures including inadequate policies, inappropriate subsidies, the fragmented nature of the country’s energy sector, the over emphasis given to conventional centralised energy provision, along with ineffective implementation and resource constraints (Balachandra 2011b).

2.3.4. Decentralised & Renewable Energy Sources

As part of its goal to achieve universal electricity access the Indian government has given priority towards decentralised energy systems for villages that are deemed too remote to be connected to the conventional centralised grid (Chaurey *et al.* 2004, Kamalapur & Udaykumar 2011), it has also been suggested that extension of India's national grid for rural electrification may not be feasible (Castellanos *et al.* 2015, Kamalapur & Udaykumar 2011). Furthermore in light of concerns surrounding energy security and climate change it is expected that renewable energy will play a significant role in the countries future energy mix (IEA 2012, MSPI 2013, Pillai & Banerjee 2009).

Several studies have shown the potential for the exploitation of various RETs in India as a means of delivering modern energy services for household activities, particular in rural and remote communities (Bhattacharya & Jana 2009, Bhide & Monroy 2011, Kamalapur & Udaykumar 2011, MSPI 2013, Nautiyal & Varun 2012, Parikh & Parikh 2011, Pillai & Banerjee 2009, Singh & Parida 2013). Particular interest is being centred on the potential of energy generation from biomass, solar, wind and small hydro projects.

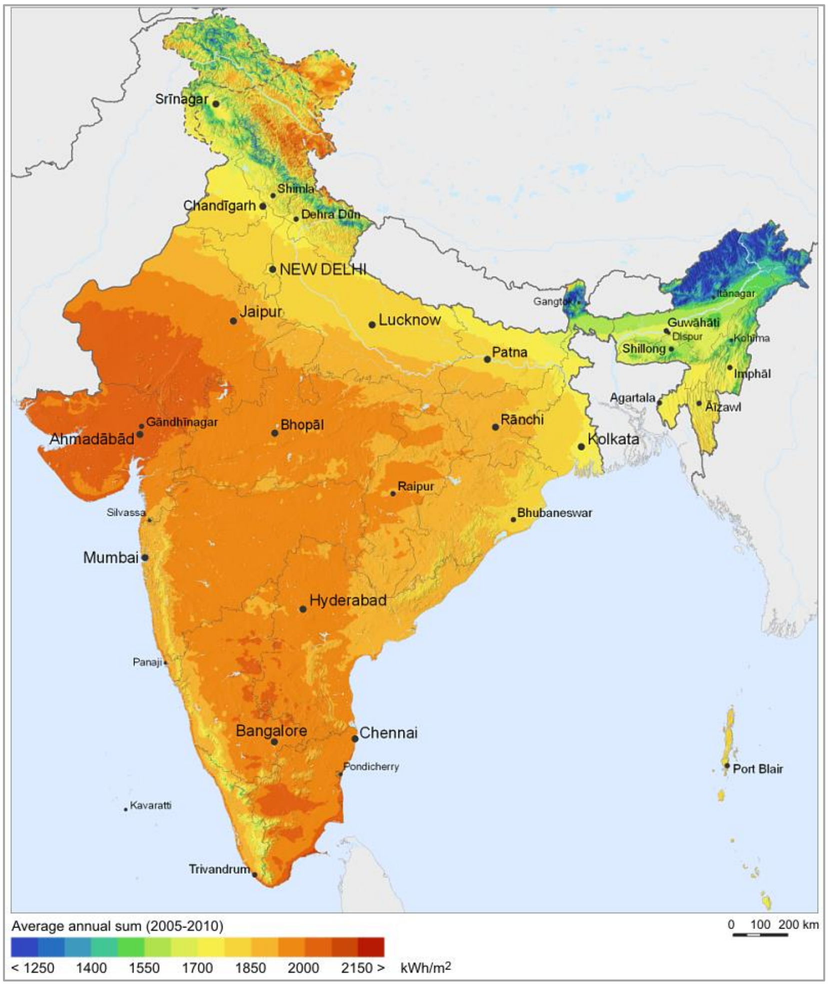
Solar power may prove to be the principal option, as annually India receives on average 7000 MJm^{-2} of solar radiation exposure (MNRE 2009). Figure 2.2 provides an overview of solar energy potential in India based off of horizontal irradiance measurements. As is shown the majority of the country has an annual potential in excess of 1700 kWh/m^2, or >4.7 kWh/m^2 per day.

So for a country with such a large and dispersed rural population decentralised power generation via RETs can help address some of the major issues being faced by the power sector and concerns surrounding the impacts of future energy demand (Hiremath *et al.* 2009).

The technical and operational feasibility of biomass decentralised power systems have been shown in India along with their acceptance by the local populace, however their economic viability within Indian has yet to be demonstrated (Hiremath *et al.* 2009).

Despite this and the considerable progress which has been made within the country in the deployment of RETs, and the effort that the Indian Government has been putting into promoting the use of these RETs systems, their application as decentralised energy resources are still limited (Hiremath *et al.* 2009).

Figure 2.2: India's solar energy potential as indicated by global horizontal irradiation levels (SolarGIS 2014)



2.3.5. Energy Policies Of India

There are several key policies (Table 2.1) that the Indian government has introduced to help reform the power supply sector, improve rural energy provision and promote the use of RETs (Balachandra 2011a, Bhide & Monroy 2011, IEA 2012, Kumar *et al.* 2010, MNCES 2005, MNRE 2002, MNRE 2010, MoF 2011, MOPI 2003, MOPI 2005, MOPI 2006a, MOPI 2006b, Szakonyi & Urpelainen 2013). These policies help address some of the issues being faced with using RETs as a means of rural energy provision, while also highlighting what the priorities are of the Indian government towards energy provision.

Table 2.1 Key energy policies introduced by Indian government

Policy	Key features
National Biogas & Manure Management Policy (2002)	- Promote the use of biogas derived from dung for household cooking in order to meet the minimum energy requirements for cooking
The Electricity Act (2003)	- Set mandatory purchase obligation for renewable based electricity systems
National Electricity Policy (2005)	- Identified decentralised energy generation as a suitable means of delivering electricity in rural areas. - Identified RETs as suitable options for decentralised energy generation
National Tariff Policy (2006)	- Requires State Electricity Regulatory Commissions to set a fixed minimum percentage for the number of state renewable purchase obligations
New and Renewable Energy Policy Statement (2005)	- Improve energy security through application of RETs - Use of RETs to supplement energy demand in remote areas - Increase use of RETs to achieve energy equality
National Rural Electrification Policy (2006)	- Recognises electricity as a basic human need essential for economic growth and poverty reduction - Requires states to prepare a rural electrification plan - Aim to achieve minimum consumption of 1 kWh per household per day by 2012 - Recommend use of off grid standalone solutions
Jawaharlal Nehru National Solar Mission(2010)	- Reduce cost of solar power generation - Target installation of 20,000 MW of solar power by 2022
National Clean Energy Fund (2011)	- Funds research and innovative projects in clean energy technologies

2.4. Summary Of Findings

Energy is essential for facilitating sustainable development and the improvement of living conditions for millions of people around the world. Particularly those living in the rural and isolated areas of developing countries who are typically found to be not just income poor but energy poor too.

There are many negative implications of using fossil based energy resources which have been clearly and extensively described in the literature. They are a finite resource and despite the continuing debate surrounding exactly when they may run out, supplies are diminishing while newer, more expensive methods of extraction are required to access them. These two factors are continuing to drive the rise in fuel prices which ultimately is passed onto the consumer.

An overview of potential RETs for decentralised energy generation highlighted specific environmental impacts associated with each which could lead to significant detrimental effects which could offset any benefits making them an unsuitable and unsustainable solution for modern energy provision in rural and remote communities

Certain RETs have the potential to be a more stable source of energy in terms of cost after the initial outlay and can present a viable economic alternative for the future while aiding universal modern energy access which drives development and help improve living conditions, particularly in rural communities where their use as a decentralised energy source has been shown to be a viable and efficient option (Chauhan & Saini 2014, Demirbas & Demirbas 2007, Mahapatra & Dasappa 2012, Mustonen 2010). As these technologies lend themselves to being used as decentralised energy resources they can also avoid some of the accessibility barriers observed as the energy generation is put at the heart of the community. Furthermore it has been noted that as these technologies can be installed close to the point of demand the costs relating to energy transport and distribution are reduced which will ultimately lower the costs to the end user (Chakrabarti & Chakrabarti 2002, Thiam 2010).

In addition to affordability and availability the selection of household fuels is also influenced by personal preferences, demographic factors, as well as the education and awareness of the those responsible for deciding which fuels are used in the household (Bhide & Monroy 2011, Reddy & Srinivas 2009). A lack of knowledge and understanding of the benefits and adverse effect of different fuels was shown to lead to uninformed fuel selection, and that improved levels of household education and income also improves a shift towards more efficient modern fuels (Bhide & Monroy 2011, Reddy & Srinivas 2009).

Jennings (2009) and Kandpal & Broman (2014) highlighted that the renewable energy sector is reliant on education in order to improve the adoption of these RETs with five vital functions of education which focus on knowledge, confidence and training (Jennings 2009, Kandpal & Broman 2014). These are the factors that have been identified as key barriers and as such any implementation of RETs in rural areas will need to include a program of education to reduce the risk of failure which has both short and long term effects on the future of renewable energy in an area.

India is a prime example of a developing country where energy poverty has become a major concern because of the impacts it is having upon economic and social development and where the use of RETs may provide a solution to overcoming these concerns while mitigating the broader global communities concerns of the challenges faced through climate change.

Comprehensive national policy that takes into account the various rural scenarios is needed. Any such policy should consider all appropriate decentralised energy generation technologies, with particular emphasis on the use of RETs, the necessary financial and regulatory arrangements required to facilitate the aforementioned solutions as well as the impacts reforms could have on existing decentralised projects and finally the relationship all the above will have to the economic and social development of rural communities (Chaurey *et al.* 2004, Hiremath *et al.* 2009).

A better understanding of the dynamics of energy access in India is needed however in order to be able to design and implement policies which enable the expansion of modern energy access and the use of RETs (Balachandra 2011a). Before any government can address these challenges it is essential to understand and have a clear insight to what the current situation is. This then enables targeted polices, programs and institutional mechanisms to be properly implemented to facilitate the uptake and access to modern energy services (Balachandra 2011a).

Chapter 3. Thesis Aims & Methodology

Based on the findings of the literature survey, the general aims of this thesis are as follows:

1. Explore the opportunities for modern energy services in India's rural communities.
2. Identify barriers that exist to the use of renewable or sustainable energy sources.
3. Assess the potential impacts associated with the use of renewable or sustainable energy sources.
4. Determine the wider environmental impacts resulting from the use of renewable or sustainable energy sources.

Objectives 1 and 2 are addressed in Chapter 4, 5 and 6 through the application of rural household energy surveys.

Objective 3 is addressed in Chapter 7 via the application of a life cycle assessment exploring the impacts associated with the need for decentralised energy storage.

Objective 4 is addressed using an integrated energy modelling tool LEAP (Long-range Energy Alternatives Planning system) in Chapter 8.

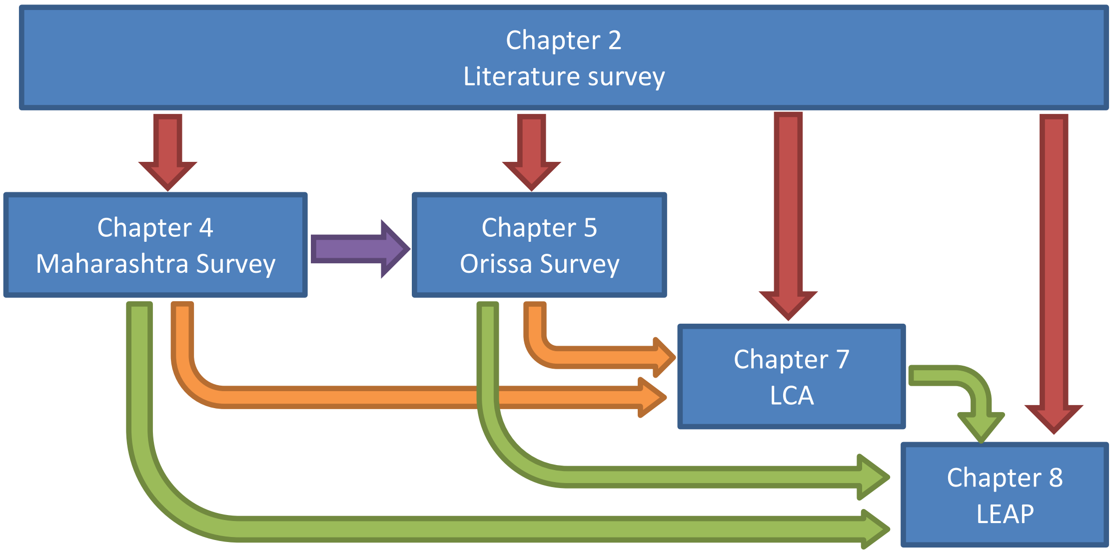
The remainder of this chapter outlines the materials and methods used in Chapter 4 – 8 to accomplish the aims and objectives of this thesis.

The results from certain approaches are also used in subsequent chapters to help fulfil further objectives. Figure 3.1 provides an overview of the relationships between different chapters and how the findings of each feeds into later work.

The findings of the literature survey feeds into all subsequent chapters with it helping guide the design of questions used in the surveying and provide primary data to aid in building the life cycle assessment and LEAP energy forecast models of Chapter 7 and Chapter 8.

The initial survey completed in Chapter 4 was accompanied by a respondent assessment form which allowed for feedback to be obtained which aided in the development of the survey completed in Chapter 5. The results of each of the rural energy surveys were used to build distinct models of an archetypical rural household outlining the types and volumes of fuels consumed for household tasks and estimating the per capita energy demand of the two regions surveyed. These values, along with information available in the literature were used in both Chapter 7 and Chapter 8 allowing various baseline scenarios to be constructed round which the models could be built. A comparison of these separate scenarios allows evaluation of how variations resulting from the scope of a population assessed changes the conclusions which can be drawn from the models.

Figure 3.1: Diagram illustrating the connections between methodologies of different Chapters



3.1. Rural Household Energy Survey

In order to explore and highlight the requirements for and attitudes of rural communities towards the delivery of modern energies, the most appropriate method of data collection is through the use of a cross sectional study with interview style questions. This method of data collection when assessing rural energy needs and attitudes has been demonstrated in several studies, (Heltberg 2004, Li *et al.* 2009, Liu *et al.* 2013, Mustonen 2010, Wijayatunga & Attalage 2003) as an acceptable means of collecting quantitative as well as qualitative data.

3.1.1. Survey Design & Methodology

Interview style surveys were selected as the means of collecting rural energy data because literacy rates among the target group were low, particularly in women (ORGC India 2001b), and interviewers could clarify questions at the time of surveying, improving the accuracy of responses.

In addition sending the survey via post was impractical and using e-resources was unsuitable due to limited or total absence of access to electronic versions of the survey. Surveying in this manner could also lead to inaccurate or incomplete responses as shown by Chandrasekar & Kandpal (2007) who found that many respondents answered only selective questions leaving others unanswered (Chandrasekar & Kandpal 2007). In addition, the use of interviewers allows confirmation that the target respondent had completed the questionnaire themselves.

Interviewers employed to complete the survey had the ability to translate the survey questions from English into the local dialect and then translated responses on the response sheet in English.

The survey was designed in Microsoft Office Word 2010 and consisted of seventy one questions split into six sections; Respondents details, Household information, Energy consumption, Fuel Consumption, Household income and expenses, and Views on renewable energy. There was a mixture of open and closed ended questions in the survey which were designed to highlight the requirements for modern energy access and the awareness of various renewable energy technologies (RETs) and the barriers for their penetration.

A cover letter specifically for the survey and a set of interviewer guidelines and notes were also produced to accompany the survey. The guidelines were developed for the interviewers to clarify each question in the survey to ensure that appropriate responses were obtained and documented correctly to reduce inaccuracies.

In addition to the survey, respondents in the first survey study (Maharashtra) were also asked to fill out an assessment form upon completion of the main survey. Interviewers were also given an assessment form to complete. These assessment forms were designed to enable feedback to be obtained from the respondents and interviewers on any issues or problems that were experienced during the completion of the survey and to suggest ways of improving the survey or the guidelines and notes provided. This would ultimately lead to an increased response rate and increased accuracy of responses for a larger sample size complted in Orissa completed in conjunction with the Indian Institute of Technology, Bhubaneswar.

3.1.2. Data Collection & Storage

The first survey sample consisted of eight households and was carried out in the village of Uddhar in the Raigarh district of the Indian state of Maharashtra on the 23rd August 2011 (see Figure 3.2). The second rural energy survey sample consisted of ninety seven households from thirteen villages, from the Khordha and Cuttack districts of the Indian state of Orissa (see Figure 3.2) and was carried out on 17-18th and 24-25th March 2012.

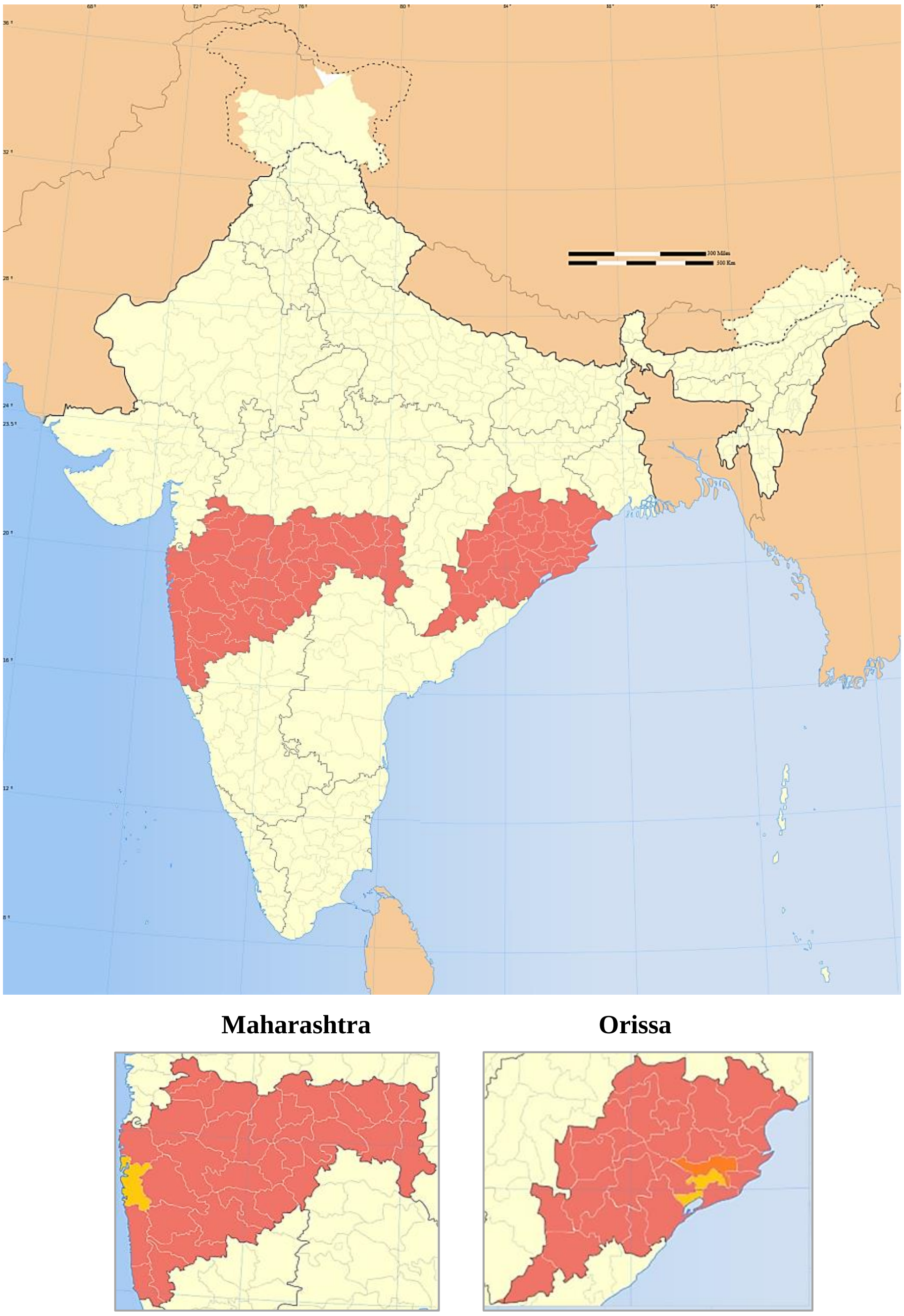
The states of Maharashtra and Orissa were selected as they represent the rest of India well. They both have large rural populations, 57.6% and 85.0% respectively, the majority of which, 59.5% and 85.5% respectively, reside in villages with a population of 2,500 or less (ORGC India 2001d). There is also significant potential for the exploitation and expanded use of various Low Carbon Technologies (LCT) for the generation of low carbon energy for household use (MSPI 2012).

The districts where the surveying was completed were selected for convenience to enable travel to and completion of the surveys in selected villages within a reasonable time frame. Villages were selected by first using stratified random sampling to select villages from a list of all villages with a population less than 2,500. From this list convenience sampling was used to select villages to facilitate the completion of the survey within one day

Selection of the households within the village to survey was random but also relied upon a respondent's willingness to participate.

The completed surveys response sheets for both studies, as well as the feedback forms from the first study, were brought back to the United Kingdom where the results were inputted into a database created in Microsoft Access 2010. The database made use of forms which had been created to have a similar layout to the survey for each section of the survey to enable simple and accurate input of data.

Figure 3.2: Map Showing Location of Maharashtra & Orissa States within India. The Location of Raigarh District within Maharashtra & the Cuttack (orange) & Khordha (yellow) Districts within Orissa (adapted from (Ganesh 2012))



3.1.3. Analysis of Survey Data

Microsoft Access queries were used to select subsets of data for appropriate statistical tests from the full dataset of each survey. IBMs Statistical Package for the Social Sciences (SPSS) (IBM 2013) was used for cross tabulation and descriptive analysis of each of the data sets and aided in developing a model of an archetypical household from the surveyed regions.

In order to improve the accuracy of the results data which were not normally distributed were transformed in order to provide geometric means. Geometric means are used to indicate the central tendency of a set of values by using the product of their values.

SPSS and the statistical program R (R Core Team 2013) were also used to carry out univariate statistical analyses to explore and highlight significant statistical relationships between variables. The aim of this was in both studies was to allowed the investigation of factors that might affect a respondent's awareness of and attitudes towards renewable energy resources.

Two variables were considered to have a statistically significant relationship if the p value calculated by the statistical test employed was equal to or less than 0.05.

The types of statistical test conducted varied due to limitations imposed by each data set, in particular sample size which restricted the use of certain statistical test. The different statistical tests conducted on each data set as well as their purpose and constraints are outlined below.

3.1.3.1. Statistical Analysis of Maharashtra Survey Data

Ten outcome variables were initially identified from section 6 of the survey (Views on Renewable Energy) to which all other variables would be compared against. These outcome variables were all binomial, with the responses being either 'yes' or 'no'. Four of the outcome variables were however dropped as all the responses were the same which made them unsuitable for statistical analysis.

Some of the independent variables were also dropped from the statistical analyses either because there were insufficient responses or because all of the responses were identical making them unsuitable for statistical analysis.

The statistical analyses used varied depending on the variables being examined. As all of the ten outcome variables were categorical, Fisher's Exact Tests were used when variables being compared to the outcome variable were categorical and Linear Discriminant Analysis (LDA) where they were continuous.

In addition to exploring the statistical relationships between the responses of the selected outcome variables and all other variables, analysis was also carried out to compare the responses of every variable that was found to be significantly associated with the outcome variables against all of the other survey variables. When these secondary outcome variables were categorical, Fisher's Exact Test and LDA were used, and when they were continuous, Pearson's Correlation and Analysis of Variance (ANOVA) was used.

This would allow for the identification of variables that were significantly associated with variables significantly associated with any of the ten selected outcome variables. Identifying such variables would potentially reveal previously hidden factors which could be influencing respondents' attitudes towards renewable energy resources.

3.1.3.2. Statistical Analyses of Orissa Survey Data

The larger number of responses in the Orissa survey allowed for different statistical test to be utilised to those used in analysing the Maharashtra data set. The statistical computing program R (R Core Team 2013) was used to carry out binomial logistic regression to explore and highlight significant statistical relationships between variables. The program also enabled Fisher's exact test to be completed when necessary to ensure accurate inferences being drawn from small data sets.

Unlike the Maharashtra analysis only six outcome variables were selected from section 6 of the survey for logistic regression analysis. All outcome variables were again binomial with the response being either 'yes' or 'no'. The responses to the other survey questions were compared against these outcome variables.

Four of the outcome variables used during the study presented in Chapter 4 were omitted from the logistic regression in this study as no significant relationships were observed between them and any other variables from the survey in this initial study.

Some survey questions were omitted from the logistic regression analyses because they did not fulfil the criteria required to be used (e.g. 1 or more categories with <10 responses, all of responses in variable being the same).

Fisher's Exact Test was used to test the significance between responses when one or more cells during cross tabulation contained less than five responses. In each case the significant relationship between two variables was determined using the most appropriate test dependent upon the statistical criteria that were met.

In some circumstances variables that were significant either as a result of the regression analysis or Fisher's Exact Test were also omitted as no conclusions could be drawn from them (e.g. where 'other' was the only significant category). Additional variable analyses were carried out when necessary to further explore the statistical relationships between independent variables and identify possible hidden factors which could be influencing respondents' attitudes towards renewable energy resources.

Appendix 1 contains the results from the statistical analysis of each outcome variable from this survey.

3.2. Life Cycle Assessment of Batteries For Energy Storage

In order to assess the environmental impact battery storage options can have when included in a decentralised RET system, a LCA is undertaken of the four main available options. In addition an evaluation of the repurposing of EOL batteries from automotive uses is completed to assess the offsetting benefits second life batteries can have.

The International Organisation for Standardisation (ISO) standards for LCA (ISO 14040 and 14044) are used as a guide for the completion of this study.

3.2.1. Goal & Scope Of LCA

The goal of the LCA completed in this study was to establish and compare the additional environmental impacts which can be attributed to a decentralised RET system through the use of various chemical energy storage systems, and explore how these impacts can offset the carbon saving made through the use of RETs.

The LCA considered the cradle-to-gate emissions emitted during the production of a battery with the functional unit being 1 kg of battery. Data was gathered from literature sources to quantify the emissions of GHGs (CH_4, N_2O, CO_2) and those which lead to localised air pollution (particulate matter (PM), volatile organic compounds (VOC), mono-nitrogen oxides (NO_x)).

The results were used to establish the total global warming potential (GWP) (tCO_2e) and volume of additional CO_2 which is attributable to a battery system suitable to meet the per capita energy demands of India's rural households using 3 different energy demand scenarios.

Furthermore the LCA explored the offsetting effect repurposing Li-ion batteries can have on reducing the carbon footprint of decentralised RET system. In order to do this, the total CO_2 avoided during the batteries primary use phase was calculated and then the volume of CO_2 offset (if any) outlined.

3.2.2. LCA Assumptions

Total emissions of individual GHGs and other selected pollutants were quantified through a cradle-to-gate LCA by Sullivan & Gaines (2012). These results are used as a basis for this study and constitute the total emissions for individual battery production from raw material extraction through to final product assembly (Sullivan & Gaines 2012).

From these quantified emissions, the total GWP of each battery was calculated by taking the GWP value of each GHG outlined by the IPCC (IPCC 2013) and converting the relative emissions from each battery into their kg CO_2e/kg and then aggregating the total value.

Energy density denotes the amount of energy that can be stored relative to a given mass and thus the battery size required to meet a set level of demand. The energy density of each battery was calculated by taking the mean from multiple literature sources (Appendix 2) (Díaz-González *et al.* 2012, Evans *et al.* 2012, Hadjipaschalis *et al.* 2009, Kousksou *et al.* 2014, Råde & Andersson 2001, Rahman *et al.* 2012, Rantik & Tekniska 1999, Rydh & Karlström 2002, Sullivan & Gaines 2010, Sullivan & Gaines 2012, Van den Bossche *et al.* 2006, Yekini Suberu *et al.* 2014).

To represent the repurposing of an EOL Li-ion battery, it is assumed that its capacity has degraded by 20.0% as is suggested in the literature (Ahmadi *et al.* 2014, Richa *et al.* 2014, Williams & Lipman 2010).

The life span of a Li-ion battery in a hybrid passenger vehicle varies considerably from 150,000 to 360,000 km (Ahmadi *et al.* 2014, Broussely 2010, Faria *et al.* 2014, Samaras 2008, Sullivan & Gaines 2012, Van den Bossche *et al.* 2006, Williams & Lipman 2010). The difference in life span impacts upon the volume of CO_2e avoided a longer life span the more CO_2e that is avoided in comparison to a conventional passenger vehicle. These batteries are however expected to last the total service life of the vehicle they are installed in and be comparable to conventional passenger vehicles. Thus in this LCA, it is assumed that the Li-ion will match the predicted service life of a passenger vehicle as specified by the EU of 200,000 km (EU 2009).

Working under this assumption and using the volume of CO_2 emitted during the use phase of a conventional and hybrid passenger vehicle presented by Ahmadi *et al* (2014), it is possible to estimate the CO_2 saving made per km and throughout the entire vehicles service life.

The methods of calculating the total carbon saving made per km by a hybrid vehicle compared to a conventional passenger vehicle is outlined in Equation 3.1 Part A. Part B summarises the total carbon saving that would be made by a hybrid vehicle meeting the EU specified service life target of 200,000 km for a passenger vehicle.

Equation set 3.2 Part A outlines the method of calculating the distance a hybrid vehicle needs to travel to offset the total carbon debt associated with its Li-ion batteries production.

The data used to calculate the total kg CO_2 emitted per km are obtained from Ahmadi *et al* (2014), with the total battery mass (M) used from Samaras (2008) when calculating total distance to offset 1 kg of Li-ion battery.

Equation 3.1:

Part A

$$\boldsymbol{A = \frac{37{,}400}{160{,}000}}$$

$$\boldsymbol{B = \frac{10{,}700}{160{,}000}}$$

$$\boldsymbol{Cs = A - B}$$

Part B

$$\boldsymbol{TCs = \frac{Cs \cdot C}{1000}}$$

A = total kg CO_2 emitted/km by conventional passenger vehicle.
B = total kg CO_2 emitted/km by hybrid passenger vehicle using Li-ion battery.
Cs = total carbon saving kg/km.
C = EU specified passenger vehicle service life distance (km).
TCs = total carbon saving across whole service life (tonnes).

Equation 3.2:

Part A

$$\boldsymbol{TCd = M \cdot GWP}$$

$$\boldsymbol{ToD = \frac{TCd}{Cs}}$$

Part B

$$\boldsymbol{D = \frac{ToD}{M}}$$

TCd = total carbon debt (kg CO_2e).
M = 252 kg (battery mass).
GWP = global warming potential (CO_2e) per kg of battery.
ToD = distance for total carbon offset of battery (km).
Cs = total carbon saving kg/km (Equation 5.1: Part A).
D = distance to offset carbon debt of 1 kg (km).

The per capita energy demand of India's rural households is measured in end-use energy demand rather than total energy consumption. Total energy is a measure of the energy used without considering levels of efficiency. End-use energy is adjusted and accounts for losses to measure actual energy used (Khandker *et al.* 2010).

The per capita energy demand was calculated using rural energy use patterns available from the Development and Research group at The World Bank (Khandker *et al.* 2010). The efficiency values used by the World Bank as well as energy consumption estimates of different appliances (O'Sullivan & Barnes 2006, Rogers *et al.* 2008) were used to calculate an estimate of the per capita energy consumption of the archetypal rural household based on the survey findings from Chapters 4 and 5 (Appendix 3). Comparisons of these separate scenarios allow evaluation of how per capita energy demand varies depending upon the scope of population being assessed. Table 3.1 provides a summary of each scenario.

Table 3.1: Scenarios for per capita energy demand comparison

	Scenario details	Scenario level
Scenario 1	National per capita energy usage of India's rural communities (Khandker *et al.* 2010)	National
Scenario 2	Typical household from Uddhar village in Raigarh district Maharashtra. Summary Chapter 4.2.7	Single village
Scenario 3	Standard household from state of Orissa. Summary Chapter 5.3.7	Single state

3.3. Long range Energy Alternative Planning system

In order to assess the impacts of using decentralised RETs in the rural communities of India, the integrated energy modelling tool LEAP (Long range Energy Alternative Planning system) was utilised.

LEAP includes a Technology and Environmental Database (TED) which collates data from a range of institutions, including the Intergovernmental Panel on Climate Change (IPCC) and International Energy Agency (IEA). This TED describes the technical characteristics, environmental impacts and emission factors of a range of energy technologies and fuels and is used during the modelling process to quantify impacts such as CO_2 emission (Heaps 2012).

LEAP was used in this study to build three models of energy usage for rural Indian communities and to explore the changes which occur in energy demand, GHG emissions and primary fuel consumption under the application of varying scenarios of energy provision.

The baseline models constructed in LEAP used the per capita energy consumption models developed in Chapter 7 (Appendix 3) and the standard Indian household models from Chapter 4.2.7 and Chapter 5.3.7. These baseline models forecast how increasing the per capita energy demand of India's rural population impacts on total energy demand, national global warming contributions and primary feedstock fuel consumption without the use of any decentralised RETs. Table 3.2 summarises the different models.

As the three models are based on different estimates of average household energy usage, it allows for the methods by which they were calculated to be compared and show how they affect estimates of total energy demand and total GHG emissions.

Table 3.2 Summary of energy model constructed in LEAP.

	Model details
Model 1	National per capita energy data and State ratios of energy consumption (Khandker *et al.* 2010)
Model 2	State per capita energy data and summary of standard Orissa household (Chapter 5.3.7)
Model 3	Village capita energy data and summary of standard Uddhar household (Chapter 4.2.7)

The three scenarios developed and applied to these models explore how substituting the current means of energy provision for various household activities with energy generated from decentralised RETs would impact on national global warming contributions, energy demand and primary fuel consumption.

The scenarios were designed by first assessing the major areas of household energy consumption in the surveys of Chapter 4 and 5. These areas were identified as cooking, lighting and the powering of appliances. The scenarios simulate the replacement of the fuels used in one or more these areas. Table 3.3 summarises the different scenarios applied to each model.

Scenario 3 combines the replacement of fuel used for lighting and other appliances as the same fuel was used in both (electricity). It is sensible to assume that the introduction of RETs to replace electricity would mean replacement in all activities in the household where it was utilised.

Table 3.3 Summary of energy scenarios applied to baseline models using LEAP.

	Scenario details
Baseline Scenario	No decentralised RETs introduced, demand met through expanded use of existing energy sources
Scenario 1	All cooking fuels replaced with RET energy sources
Scenario 2	All lighting fuels replaced with RET energy sources
Scenario 3	All lighting fuels and fuels used for other appliances (excluding cooking) replaced with RET energy sources

3.3.1. LEAP Model Assumptions

Each of the three baseline models created in LEAP explored the changes in global warming potential (GWP), total energy demand and primary feedstock fuels that would occur with increasing per capita energy demand of India's rural population from their current levels to the UN mean per capita of 21.98 MWh (UN-Data 2014) within an eleven year period. In all of the models the starting baseline per capita energy demand uses total energy rather than end energy.

The Parameters used in LEAP to create each individual baseline energy model of rural Indian households extrapolated from varying population assessments are outlined in Tables 3.4 to 3.6. 2011 is the start year and is the point before any RETs are introduced. The first modelling year is 2012 and the point by which half of the rural population has been provided with RETs is referred to as the end year which in these models is 2022.

The mean household size used for the national baseline model was taken from the most recently available Indian census (ORGC India 2001a). The levels of fuel consumption for the national baseline model were calculated by applying the equivalent ratios from the state baseline model in order to meet the national per capita energy demand.

According to the 2001 Indian census there are 574,875 rural households (ORGC India 2001e) this value was used in each of the baseline models to represent the total population. The mean number of occupants per household varied depending upon individual model parameters. For each scenario only half of these rural households were assumed to have been provided with decentralised RETs as a substitute energy source by the end year.

Table 3.4: Parameters used in LEAP to create baseline energy model of rural Indian households for Model 1.

Parameter	Units	Start year value	End year value
Household size	People	5	5
Number of households	Households	574,875	574,875
Per capita (pc) energy demand	kWh/pc	2356.63	21,977.21
Energy intensity – Household Lighting			
Electricity	kWh/pc	49.67	463.17
Kerosene	kWh/pc	192.68	1,796.86
Energy intensity – Household Cooking			
Biomass (inc firewood)	kWh/pc	1774.93	16,552.40
Kerosene	kWh/pc	105.73	985.96
Energy intensity – Other appliances			
Electricity	kWh/pc	233.64	2178.82

Table 3.5: Parameters used in LEAP to create baseline energy model of rural Indian households Model 2.

Parameter	Units	Start year value	End year value
Household size	People	6	6
Number of households	Households	574,875	574,875
Per capita (pc) energy demand	kWh/pc	1,446.50	21,977.21
Energy intensity – Household Lighting			
Electricity	kWh/pc	30.72	466.75
Kerosene	kWh/pc	119.18	1,810.75
Energy intensity – Household Cooking			
Biomass (inc firewood)	kWh/pc	1097.87	16,680.34
Kerosene	kWh/pc	65.40	993.58
Energy intensity – Other appliances			
Electricity	kWh/pc	133.33	2025.766

Table 3.6: Parameters used in LEAP to create baseline energy model of rural Indian households Model 3.

Parameter	Units	Start year value	End year value
Household size	People	4	4
Number of households	Households	574,875	574,875
Per capita (pc) energy demand	kWh/pc	1,746.26	21,977.21
Energy intensity – Household Lighting			
Electricity	kWh/pc	104.09	1,309.99
Kerosene	kWh/pc	643.06	8,093.09
Energy intensity – Household Cooking			
Biomass (inc firewood)	kWh/pc	925.17	11,643.59
Energy intensity – Other appliances			
Electricity	kWh/pc	73.93	930.53

To ensure India's energy mix was accurately represented in the model the composition of the country's electricity grid mix as described by the Indian Ministry of Power (MOPI 2014) and the transmission and distribution losses which occur with centralised energy generation were included. According to the Indian Ministry of Power transmission and destitution losses are estimated to be around 23.65% (MOPI 2014).

The use of solar and wind based RETs were outlined previously as the most suitable technologies for meeting the modern energy needs of rural communities. Furthermore the Indian Ministry of Statistics and Programme Implementation has shown that there is substantial potential for the expended use of wind and solar energy technologies across India (MSPI 2013). As the potential for energy generated from solar sources is far greater than wind (E&Y 2013, MSPI 2013), a larger emphasis is put on the expanded use of solar power in the scenarios where decentralised RETs are used to replace current energy sources, with the final end share being 75.0% solar and 25.0% wind.

Chapter 4. Rural Household Energy Survey; Uddhar Village, Maharashtra

4.1. Introduction

Despite being an important barrier to the successful implementation of energy projects in rural areas (Moomow *et al.* 2011, Painuly 2001), the attitudes of stakeholder communities to the introduction and use of any form of modern energy over conventional means is often overlooked. Obtaining detailed information from developing countries regarding energy access in rural and remote areas is difficult as it is not always readily available and in some cases the data does not exist.

An extensive search of the literature found no studies on the attitudes of rural communities in India towards modern energy services supplied by renewable or sustainable energy resources.

This chapter presents the results for the completion of a rural energy survey completed in Maharashtra, India. The aim of the study was to gather primary data from a rural community relating to their current energy requirements and their attitudes towards modern energy sources with particular focus on renewable and sustainable sources, and the opportunities and barriers for their expanded use. In addition, the study was used as a pilot to test the methodologies suitability and the survey, ultimately leading to an increased response rate and improved accuracy in responses from a larger sample size.

4.1. Methods & Approach

The methods and approaches undertaken in the completion of the rural energy survey described in this chapter, and how the data was collected and subsequently analysed can be found in Chapter 3.1.

4.2. Rural Energy Survey Results

Descriptive Analysis

4.2.1. Respondent Demographics

The survey consisted of 8 respondents from the Raigarh district; all of the respondents came from the village of Uddhar. The youngest respondent was between 26-30, the oldest was 56-60. The most common age group was 46-50 *(37.5%, n=3)*. A full breakdown of the different respondent age groups is show in Table 4.1. The gender of the respondents was an even split with 50.0% *(n=4)* being male and 50.0% *(n=4)* being female.

Table 4.1: Composition of individual respondent age

Age Group	Frequency	%
26 - 30	1	12.5
31 - 35	2	25.0
46 - 50	3	37.5
51 - 55	1	12.5
56 - 60	1	12.5
Total	8	100.0

4.2.2. Household Information

The mean number of permanent occupants living in each household was 3.6 (range 2-5). The most common household size was 4 *(37.5%, n=3)* permanent occupants.

Of the households surveyed, 87.5% *(n=7)* indicated that the head of the household was male and 12.5% female. However none of the respondents indicated that the head of the household was solely responsible for deciding which fuels are used in the household. Instead in the majority of cases the decision was a shared responsibility *(75.0%, n=6)*. The remaining respondents indicated it was either their wife *(12.5, n=1)* or no one's responsibility *(12.5%, n=1)*.

All of the households surveyed were single storied buildings, with the majority having just one entrance *(75.0%, n=6)*, the mean number of entrances was 1.2. In all cases the entrances were covered. Households with five windows were the most common *(50.0%, n=4)*, with the mean being 4.3 windows per household. 37.5% *(n=3)* of households left their windows open permanently.

The survey showed that households with three rooms *(50.0%, n=4)* were the most common, followed by those with two rooms *(25.0%, n=2)*. The mean was three rooms per household (range 2-5).

Tiles *(50.0%, n=4)* were the main materials used for roofing followed by steel *(25.0%, n=2)* and mud *(25.0%, n=2)*. The most widely used materials for constructing household walls were mud *(62.5%, n=5)* and bricks *(50.0%, n=4)*. The main material used for household flooring was mud *(62.5%, n=5)*. Tiles were also commonly used flooring materials for 37.5% *(n=3)* of respondents.

87.5% *(n=7)* of respondents indicated that they kept livestock. Of these respondents 85.7% *(n=6)* kept cattle and 28.6% *(n=2)* kept one or more buffalo. The mean number of animals per household was 1.4 and the most common was 1.0 animal per household (range 1-3).

62.5% of respondents grew their own crops. Rice is by far the most popular crop grown with 100% *(n=5)* of these respondents identifying it as a crop they grew. It also accounts for 85.0% of the total area used by respondents to grow crops. Only one respondent *(20.0%)* indicated growing *'Other'* crops.

The number of acres allocated for rice growth by individual respondents ranges from a minimum of 1.0 acre to a maximum of 8.0, with the mean being 2.6 acres. The maximum total area any one respondent had for crop growth was 11.0 acres. The most common area of land used by those growing their own crops was 2.0 acres *(40.0%, n=5)*. On average household that indicated growing their own crops had access to 2.8 acres each. When including those who did not grow their own crops, each household in the sample has access to 1.4 acres of land.

4.2.3. Household Energy Usage

Energy For Lighting

Electricity was identified by all respondents as their main energy resource for household lighting. The main reasons given for why this energy resource was used over others was because it is 'easy to use' *(100.0%, n=8)* and 'easily available' *(50.0%, n=4)*.

None of the respondents indicated that they were happy using this energy resource as their primary energy for lighting. The reasons given for this dissatisfaction are shown in Table 4.2. 87.5% *(n=7)* of respondents provided 'expensive' as an explanation for being unhappy. 25.0% *(n=2)* of respondents also indicated that they were unhappy with this fuel because they thought it was 'unreliable'. A further 12.5% *(n=1)* gave other nondescript reasons for being unhappy with using this fuel source.

Considering the general dissatisfaction of respondents with the use electricity for household lighting it is unsurprising that in addition to this primary fuel all of the respondents indicated that they made use of at least one alternative energy resource for household lighting. Table 4.3 shows the alternative energy resources used by respondents, the most popular alternative being candles, used by 87.5% *(n=7)* of respondents, followed by paraffin/kerosene *(75.0%, n=6)* and then firewood/biomass *(62.5, n=5)*.

The reasons given for when they make use of these alternative fuels over their primary energy resource are shown in Table 4.4. 87.5% *(n=7)* of respondents indicated that did so ‘during power cuts’. A further 12.5% *(n=1)* gave ‘other’ nondescript reasons for using alternative energy resources.

Interestingly despite power cuts being the main reason for why alternatives were used for household lighting, only 25.0% cited ‘unreliable’ as a reason for being unhappy with electricity as their primary resource, compared to the 87.5% who gave ‘expensive’ as their main reason for being unhappy with electricity as their primary energy resource. It could therefore be speculated that the cost of an energy resource is a more importance factor to a respondents than reliability when it comes to selecting which energy resource to use.

Table 4.2: Reasons unhappy with main fuels used for rural household lighting

		Main Energy Resource Used for Household Lighting	
		Electricity (%) *(n=8)*	Total (%) *(n=8)*
Reasons Unhappy With Selected Fuel Used	Expensive	87.5	87.5
	Unreliable	25.0	25.0
	Other	12.5	12.5
	Total	100.0	100.0

Table 4.3: Primary & alternative energy resources used for rural household lighting

		Main Energy Resource Used For Household Lighting	
		Electricity (%) *(n=8)*	Total (%) *(n=8)*
Alternative Fuels used For Household Lighting	Candles	87.5	87.5
	Firewood/Biomass	62.5	62.5
	Paraffin/Kerosene	75.0	75.0
	Total	100.0	100.0

Table 4.4: Reasons for using alternative energy resource over primary for rural household lighting

		Main Energy Resource Used For Household Lighting	
		Electricity (%) *(n=8)*	Total (%) *(n=8)*
When is Alternative Energy Resource Used	During Power Cuts	87.5	87.5
	Other	12.5	12.5
	Total	100.0	100.0

Respondents were asked to give details of the fuels they had access to but did not make use of either for household lighting and the reasons why they were not used.

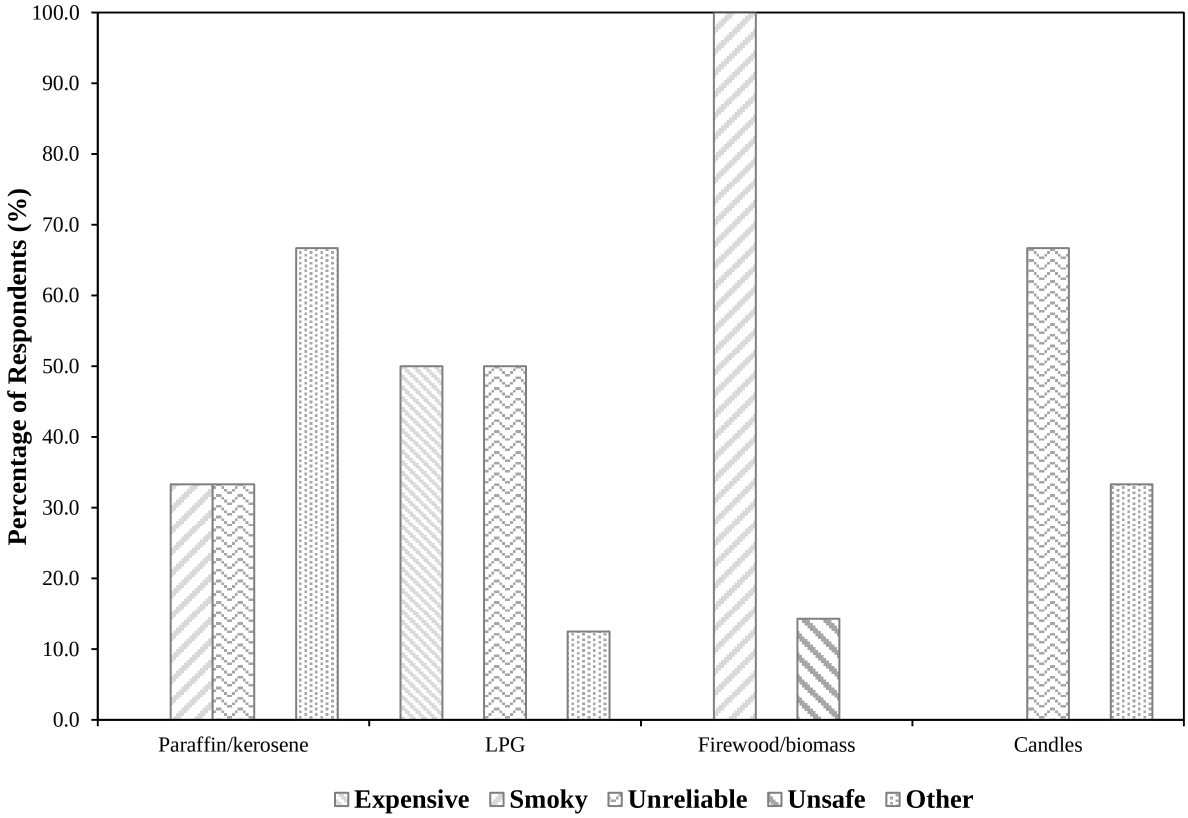
All of the respondents indicated that they had at least one other energy resource available to them that they could use for household lighting but chose not to. All of the respondents *(100.0%, n=8)* had access to LPG, 87.5% *(n=7)* to firewood/biomass resources and 37.5% *(n=3)* to both candles and paraffin/kerosene respectively.

Figure 4.1 shows the reasons respondents gave for not using these alternative fuels for household lighting despite their availability. Respondents who had access to LPG gave 'expensive' *(50.0%, n=4)* and 'unreliable' *(50.0%, n=4)* as reasons for not using it for household lighting. 12.5% *(n=1)* of respondents also gave other nondescript reasons. All of the respondents who chose not to use firewood/biomass did so because it was considered 'smoky' *(100.0%, n=7)*. A further 14.3% *(n=1)* of respondents chose not to use firewood/biomass because they deemed it 'unsafe'.

The reasons why respondents chose not to use paraffin/kerosene for household lighting were because it was 'smoky' *(33.3%, n=1)* and 'unreliable' *(33.3%, n=1)*. 66.7% *(n=2)* of respondent who had access to paraffin/kerosene gave nondescript reasons for why they chose not to use it.

Respondents chose not to use candles for household lighting despite their availability because they were 'unreliable' *(66.7%, n=2)*. Other nondescript reasons were given by 33.3% *(n=1)* of respondents.

Figure 4.1: Reasons Given Why Respondents Chose Not To Use Alternative Fuels That Were Available For Rural Household Lighting



87.5% *(n=7)* of respondents used non-natural lighting in the morning during both the summer and winter periods respectively. The length of time this lighting was used varied slightly between the two seasons; during the winter the mean time non-natural lighting was used for was 2.0 hours per day (range 1.5-3hrs). During the summer the mean length of time non-natural lighting was used for dropped slightly to 1.7 hours per day (range 1-2hrs). Two hours per day was the most common length of time non-natural lighting was used during winter *(42.9%, n=3)* and summer *(71.4%, n=5)* mornings.

Only 42.9% *(n=3)* of the respondents who completed this question used non-natural lighting for longer periods in the winter compared to the summer. On average the increase was 0.6 hours per day. The remaining 57.1% *(n=4)* of respondents usage stayed the same between both periods.

All of the respondents indicated using non-natural lighting at night during both summer and winter. The average length of time lights were used for was 4.4 hours per day during the winter and 4.1 hours per day during the summer.

The use of non-natural lighting at night during both winter and summer ranges from 3.0-6.0 hours per day with the most common lengths of times to light the house being

4.0 *(37.5%, n=3)* and 5.0 *(37.5%, n=3)* hours per day in the winter, and 4.0 *(62.5%, n=5)* hours per day in the summer.

Artificial lighting was used by 87.5% *(n=7)* of respondents to enable additional work to be carried out at night that would contribute to the household income. This additional lighting allowed on average an additional 1.3 people to work in each household for on average an additional 3.1 hours per day per household. This means that per week artificial lighting allowed for an additional 21.8 hours of productive work per household.

Each respondent was also asked to give details of the specific light sources they use. All of the respondents *(100.0%, n=8)* indicated making use of electrical lights in one form or another. 87.5% *(n=7)* used fuel lamps or lanterns and 25.0% *(n=2)* used candles.

Each household used on average 7.1 electric lights (range 4-11). The mean number of lamps and/or lanterns used was 1.2 per household (range 1-2), consuming an average of 0.72 litres of fuel per day (range 0.25-1.5L). Of the respondents who indicated using candles for household lighting, one provided a figure for the quantity used; 3 per day.

Each of the respondents who used electric lights were asked to provide details of the types of different lights they use and if possible their wattage (per hour). Fluorescent lights were the most popular with 87.5% *(n=7)* of respondents using them followed by energy saving lights *(75.0%, n=6)*, and then filament (incandescent) lights *(25.0%, n=2)*.

Table 4.5 provides an overview of the different lights used in the rural households and a count based on their wattage. Fluorescent lights had the highest count of individual lights and were the most common type of light used *(n=27)*. The most numerous single light source used were the 9 watt energy saving light bulbs *(n=22)*.

Looking at the composition of electric lights used across the sample, a combination of energy saving and fluorescent lights were the most popular; with 62.5% *(n=5)* of respondents indicating this combination in their households.

Table 4.5: Count of electric lights used in rural household for lighting

		Types of Lights Used						
		Energy saving		Filament (incandescent)		Fluorescent		
		Number of Lights	Total respondents (%) *(n=6)*	Number of Lights	Total respondents (%) *(n=2)*	Number of Lights	Total respondents (%) *(n=7)*	Total lights per wattage
Wattage of lights used	40	0	n/a	5	50.0	7	42.9	12
	9	22	83.3	2	50.0	0	n/a	24
	Other	4	16.7	0	n/a	20	57.1	24
	Total	26	100.0	7	100.0	27	100.0	60

Energy For Cooking

The mean time spent cooking in each household was 4.4 hours per day (range 3.5-6hr). All of the respondents indicated that their primary energy resource used for household cooking was either firewood/biomass *(62.5%, n=5)* or LPG *(37.5, n=3)*. The reasons respondents gave for deciding to use these energy resources are summarised in Table 4.6. Those that used firewood/biomass as their primary energy resource did so because it was 'cheap' *(100.0%, n=5)*, a 'familiar fuel' *(80.0%, n=4)* and 'easily available' *(40.0%, n=2)*. None of the respondents indicated that firewood/biomass was 'easy to use' which was the main reason given by respondents for using LPG *(66.7%, n=2)*. 33.3% *(n=1)* selected LPG as it was 'easily available'.

None of the respondents were happy with their primary energy resource for cooking. The reasons given for being unhappy with their primary fuel are shown in Table 4.7. The reasons respondents who used firewood/biomass for cooking were unhappy were because the fuel was 'too smoky' *(80.0%, n=4)* and took 'too long to burn' *(20.0%, n=1)*. Interestingly these issues highlighted by the respondents were centred on its ease of use, which was not given by any as a reason for using this fuel but was the main reason given for using LPG. The reasons given by respondents whose primary energy resource for cooking was LPG were because it was 'expensive' *(66.7%, n=2)* and unreliable *(33.3%, n=1)*.

Despite all the respondents being unhappy with their primary cooking fuel, only 87.5% *(n=7)* indicated that they made use of alternative for household cooking. Of these, are all of the respondents who used LPG *(n=3)* and 80.0% *(n=4)* of those who used firewood/biomass.

Table 4.8 shows that the two main fuels used for cooking were also the two main alternative fuels with 80.0% *(n=4)* of the respondents that selected firewood/biomass as their main fuel selecting LPG as an alternative used, and 100.0% *(n=3)* of the respondents who used LPG as their main fuel used firewood/biomass as an alternative. This suggests that the most popular fuels used for household cooking are a combination of LPG and firewood or biomass, as 87.5% *(n=7)* of respondents indicated that they utilise both as either their primary or alternative fuel.

No specific reasons were given by respondents for why they used these alternatives over or in addition to their primary energy resource for cooking. However in most cases it depended upon what was being cooked or the speed at which food needed to be prepared.

Table 4.6: Reasons for selecting main fuel used for rural household cooking

		Main Energy Resource Used For household Cooking				
		Firewood/ biomass (%) *(n=5)*	Total respondents (%) *(n=8)*	LP Gas (%) *(n=3)*	Total respondents (%) *(n=8)*	Total (%) *(n=8)*
Reasons For Selected Fuel Used	Cheap	100.0	62.5	0.0	0.0	62.5
	Easily available	40.0	25.0	33.3	12.5	37.5
	Easy to use	0.0	0.0	66.7	25.0	25.0
	Familiar fuel	80.0	50.0	0.0	0.0	50.0
	Total	100.0	62.5	100.0	37.5	100.0

Table 4.7: Reasons unhappy with main fuels used for rural household cooking

		Main Energy Resource Used for Household Cooking				
		Firewood/biomass (%) *(n=5)*	Total respondents (%) *(n=8)*	LP Gas (%) *(n=3)*	Total respondents (%) *(n=8)*	Total (%) *(n=8)*
Reasons Unhappy With Selected Fuel	Expensive	0.0	0.0	66.7	25.0	25.0
	Smoky	80.0	50.0	0.0	0.0	50.0
	Takes too long to burn	20.0	12.5	0.0	0.0	12.5
	Unreliable	0.0	0.0	33.3	12.5	12.5
	Other	60.0	37.5	0.0	0.0	37.5
	Total	100.0	62.5	100.0	37.5	100.0

Table 4.8: Primary & alternative energy resources used for rural household cooking

		Main Energy Resource Used for Household Cooking				
		Firewood/biomass (%) *(n=5)*	Total respondents (%) *(n=8)*	LP Gas (%) *(n=3)*	Total respondents (%) *(n=8)*	Total (%) *(n=8)*
Alternative Fuels Used For Household Cooking	Firewood/biomass	0.0	0.0	100.0	37.5	37.5
	LP Gas	80.0	50.0	0.0	0.0	50.0
	Paraffin/kerosene	40.0	25.0	33.3	12.5	37.5
	No other source used	20.0	12.5	0.0	0.0	12.5
	Total	100.0	62.5	100.0	37.5	100.0

The average household consumption of paraffin/kerosene was 4.4 litres a month (range 4.0-6.0L), with 4.0 litres per month being the most common level of consumption *(75.0%, n=3)*.

Respondents who utilised LPG for household cooking on average consumed 6.4 litres per month (range 2.4-10.9L). The most common levels of consumption were 5.8 litres *(33.3, n=2)* and 10.9 *(33.3, n=2)* litres per month.

The average volume of firewood/biomass consumed by respondents for household cooking was 69.0 kg per month, and ranged from 44.0 kg-80.0 kg per month. With 80.0 kg being the most frequent level of monthly consumption *(66.7%, n=4)*.

75.0% *(n=6)* of the respondents had access to at least one other energy resource that could be used for household cooking but they chose not to use. Electricity was available to 66.7% *(n=4)* of respondents, both candles and paraffin/kerosene to 50.0% *(n=3)* and firewood/biomass to 16.7% *(n=1)*.

The reasons given by the respondents who had access to paraffin/kerosene but chose not to utilise it were because it was 'not easily available' *(66.7%, n=2)*, and 33.3% gave nondescript reasons *(n=1)*. Those with access to electricity and did not use it because this resource was 'expensive' *(100.0%, n=4)*. 33.3% *(n=1)* of respondents who chose not to use candles did so because it was unreliable, a further 66.7% *(n=2)* did so for other nondescript reasons. The one respondent who chose not to use firewood/biomass did so because the fuel is 'smoky' as well as other nondescript reasons.

Energy For Heating & Cooling

None of the respondents indicated needing to heat their household during the winter or summer. However all of the respondents indicated that they use air-conditioning, such as fans to cool the house during both summer and winter. Only one respondent *(12.5%)* did not use equipment that was powered by electricity to cool the house, the remaining 87.5% *(n=7)* did.

During the summer, the time spent cooling the household ranged from 4.0 hours per day to 18.0 hours per day, the mean being 9.5 hours per day. During the winter the time spent cooling the household ranged from a 2.0 hours per day to 9.0 hours per day. The mean time in the winter was 5.2 hours per day.

Other Energy Usage

Additional energy resources were not needed by any of the respondents to carry out or complete any other household tasks.

All of the respondents had access to electricity with the national or state grid being the main means by which it was accessible with all respondents *(100.0%, n=8)* citing this a source. The use of a local village or personal generator were also sources of electricity for 25.0% *(n=2)* of respondents respectively, and 12.5% *(n=1)* of respondents used batteries as a means of accessing electrical energy resources.

Despite all households having access to electricity, the length of time each household had had this access varied (range 11.0-40.0yrs, mean=22.6yrs).

4.2.4. Household Fuel Consumption

Each respondent was asked to give details on how much they spent on fuel for household tasks. Table 4.9 provides an overview of the monthly fuel expenditure and the number of respondents who indicated that their monthly expenditure included said fuel. A conversion of 1 INR = 0.0123 GBP was used to transform the values given by respondents into pounds sterling.

Table 4.9 Household expenditure for individual fuels & number of respondent whose monthly expenditure included said fuel

		Number of respondents (%) *(n=8)*	Spend per month (GBP)		
			Mean	Range	
				Min	Max
Household fuel	Firewood/biomass	87.5	2.97	2.09	3.69
	LPG	75.0	2.20	0.62	5.54
	Paraffin/kerosene	50.0	0.83	0.31	2.46
	Electricity	100.0	3.77	1.72	18.46
	Other	50.0	0.73	0.62	0.86

Firewood, electricity, and LPG were the main fuels identified by respondents which required monthly expenditure.

Respondents who used electricity had the highest average spent of 3.77 GBP per month (range 1.72 GBP to 18.46 GBP per month). The average expenditure on firewood/biomass fuel resources was 2.97 GBP per month (range 2.09 GBP to 3.69 GBP per month). Monthly expenditure on LPG average at 2.20 GBP per month (range 0.62 GBP to 5.54 GBP per month).

Total household fuel expenditure ranged from 3.94 GBP to 25.84 GBP (per month, with the mean monthly expenditure being 8.98 GBP per month.

50.0% *(n=4)* of respondents indicated that they did not buy all of the fuel they used for household activities. In all cases the 'free' fuel was either firewood or biomass, which was collected from livestock or the nearby jungle. No volumes were given by respondents for how much 'free' fuel was obtained.

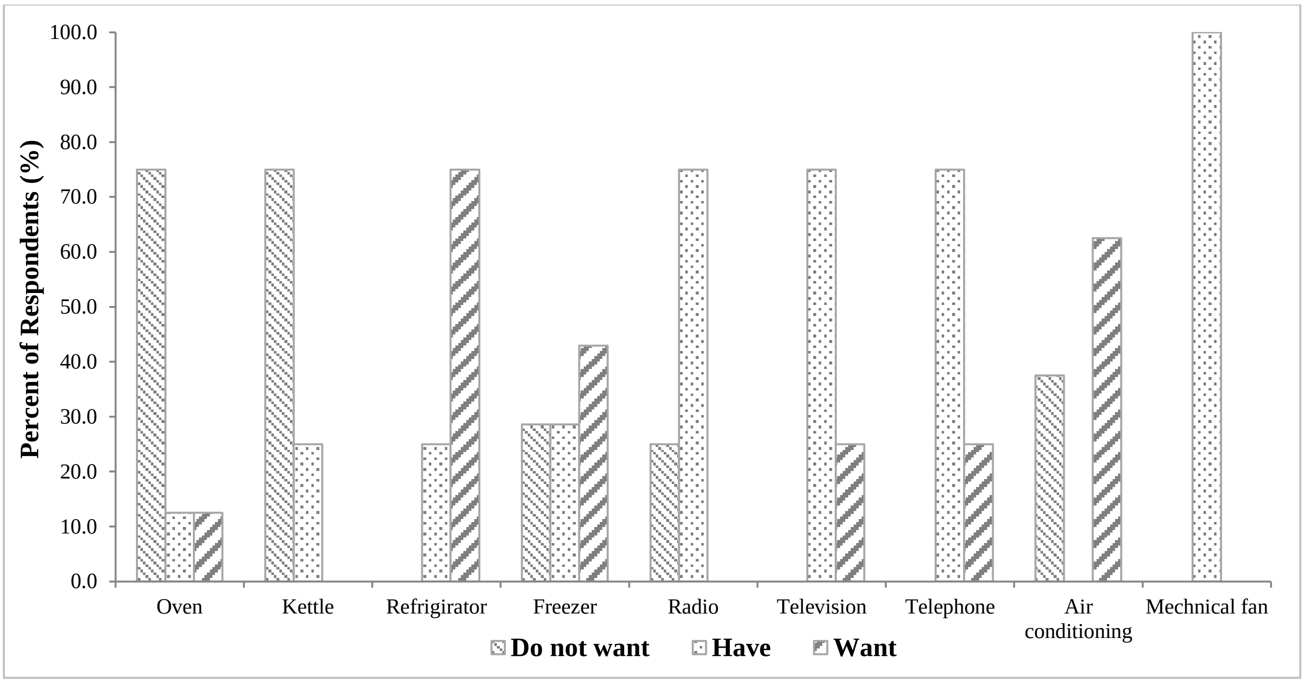
When asked how their fuel usage differed between winter and summer 75.0% *(n=6)* of respondents indicated that their fuel usages decreased during the winter, 12.5% *(n=1)* said that it increased and 12.5% *(n=1)* said that their usage stayed the same.

Respondents were given a list of common household appliances from which they were asked to indicate which they owned, would like to own or had no interest in owning and if so why. The position respondents took towards each appliance is shown in Figure 4.2. Many households had appliances such as a radio *(75.0%, n=6)*, television *(75.0%, n=6)* and telephone *(75.0%, n=6)*.

The majority of respondents indicated not wanting an oven or a kettle. 'Not needed' was the reason given by the majority of these respondents *(oven 100.0%, n=6 and/or kettle 66.7%, n=4)*.

The most sought after appliances that respondents desired to own were refrigerators *(75.0%, n=6)*, air conditioning *(62.5%, n=5)*, and freezers *(42.9%, n=3)*.

Figure 4.2: Respondents position on household appliances.



4.2.5. Household Income & Expenses

As well as the monthly expense of fuel consumed to complete household tasks, respondents indicated that household expenses also included food, transport, education, clothes and health care. Table 4.10 provides an overview of these monthly expenditures and the number of respondents who indicated their monthly expenditure included them.

Table 4.10: Household expenditure & number of respondent whose monthly expenditure included noted expense

		Number of respondents (%) *(n=8)*	Spend per month (GBP)		
			Mean	Range	
				Min	Max
Monthly expense	Food	100.0	36.32	14.77	196.89
	Transport	100.0	4.23	0.98	14.77
	Education fees	75.0	13.48	6.15	19.69
	Clothing	75.0	2.89	2.05	6.15
	Healthcare	100.0	2.94	2.05	4.92

Monthly food costs were the main expense for the household, with the mean spend being 36.32 GBP per month (range 14.77 GBP to 196.89 GBP per month)

Education fees were also a major household expense with the average cost being 13.48 GBP per month. Although more respondents indicated that their monthly expenditure included healthcare and transport costs the average monthly expense of these (health care 2.94 GBP, transport 4.23 GBP) were less than a third of the monthly expense associated with educational fees.

The average total household expenses (excluding fuels costs) was 60.63 GBP per household per month, (range 28.06 GBP to 219.04 GBP per household per month).

Across all the households surveyed, there were a total of 16 people, (8 female, 8 male) who contributed towards the household's income through some form of paid employment.

Per household the average number of people in paid employment ranged from 40.0% to 66.7% of total permeant occupants. The average being 1.9 people per household, with 2 people in paid employment being the most common *(75.0%, n=2).*

All of the respondents *(100.0%, n=8)* indicated having 1 male employed and contributing to the household income. 87.5% *(n=7)* of respondents indicated having a female member of the household contributing to the household income through paid employment, with the mean being 1.1 per household and the most common being 1 female per household *(85.7%, n=6)* (range 1-2).

The average combined number of hours worked per week by all members of a household was 96.81 hours per week per household and ranged from 57.5 to 250.0 hours per week.

The results show that the number of hours worked by the individual varied based on their gender, with males working on average 72.0 hours per week and females 25.5 hours per week.

The number of hours males spent undertaking paid employment ranged from 56.0 to 80.0 hours per week, with the most common being 80.0 hours per week *(50.0%, n=4)*. The number of hours individual females spent per week completing paid employment ranged from 1.5 to 90.0 hours per week, with 90.0 *(33.3%, n=2)*.

Variation is also seen in female and male weekly wages. The average female earns 3.73 GBP per week (range 2.77 GBP to 6.15 GBP). Whereas the average weekly wage of males was 17.80 GBP per week, (range 9.84 GBP to 27.69 GBP).

Per hour of paid employment the female members of the survey earned 40.9% less than their male counterparts who earned on average 0.25 GBP per hour compared to females who earned approximately 0.15 GBP per hour.

The total weekly household income as a result of paid employment ranged from 12.61 GBP to 27.69 GBP per week. The average total income being 20.02 GBP per week.

In addition to paid employment 12.5% *(n=1)* of respondents indicated that they had additional household income from other sources. The addition of this extra money changes the average total household income to 20.50 GBP per week.

Each respondent was asked to give details on the amount of time different members of the household spent completing tasks when not working, such as cooking and collecting water. In total details for activities completed by 28 individuals were provided, 15 male and 13 female.

Only four females *(30.5%)* spent time collecting water, with 35 hours per week in total spent on this activity. The mean time any one person spent collecting water was 8.3 hours per week (range 7.0-14.0hrs).

In total 352 hours per week were spent in education by eleven respondents, 6 male *(40.0%)* and 5 female *(38.5%)*. On average the males in education spent 24.7 hours per week completing this activity (range 7.0-56.0hrs). The female members of the household spent slightly less time in education with an average of 21.7 hours per week (range 5.0-53.0hrs).

A similar number of males *(80.0%, n=12)* and females *(84.6%, n=11)* spent time completing recreational activities. In total 264 hours per week per household was spent on recreational activities by both male and female household members. On average however males spent slightly longer on this activity (11.1 hours per week) than females (10.0 hours per week). Although across the sample the time spent on recreational activities by females had a larger range (3.0-21.0hrs per week) compared males (range 2.0-16.0hrs per week).

Only a total of 16.0 hours per week was spent by household members collecting firewood, of which 10.0 hours was completed by 23.1% *(n=3)* of females and 6.0 hours by just 1 male *(6.7%)* household member. The number of hours spent collecting firewood by females ranged from 2.0 to 6.0 hours per week, with the average being 2.9 hours per week.

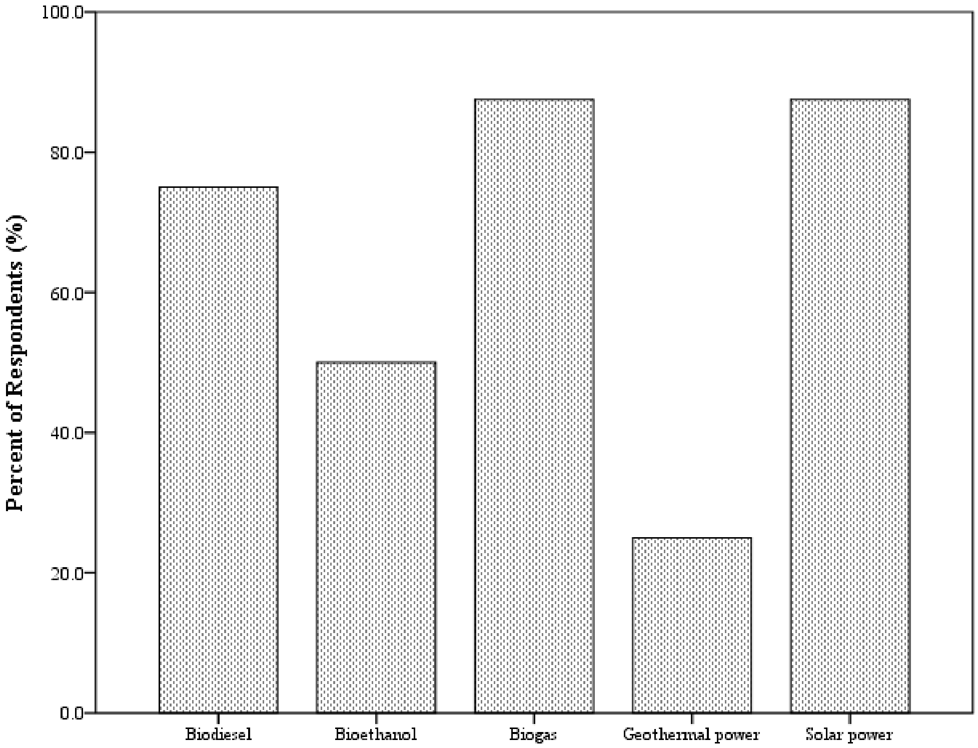
Other nondescript activities upon which time spent accounted for a total of 41.0 hours per week were completed by just 1 male *(6.7%)* and 2 female *(15.4%)* household members, with female hours accounting for 35.0 hours of the total time spent.

4.2.6. Respondents Views On Renewable Energy

When asked if they were aware of the term ‘renewable or sustainable energy’ all of the respondents *(100.0%. n-8)* were aware. Of these, however, only 50.0% *(n=4)* were able to provide a definition for what they believed ‘renewable or sustainable energy’ to be.

All of the respondents were able to name at least one example that they had heard of, Figure 4.3 shows the examples that respondents were able to identify. Biogas and solar power were the most prevalent examples given with 87.5% *(n=7)* of respondents giving them as examples. Biodiesel was the next most popular example with 75.0% *(n=6)* of respondents citing it. Bioethanol and geothermal power were given as examples of renewable or sustainable energy sources by 50.0% *(n=4)* and 25.0% *(n=2)* of respondents respectively.

Figure 4.3: Renewable energy resources identified by respondents who indicated prior awareness of the term.

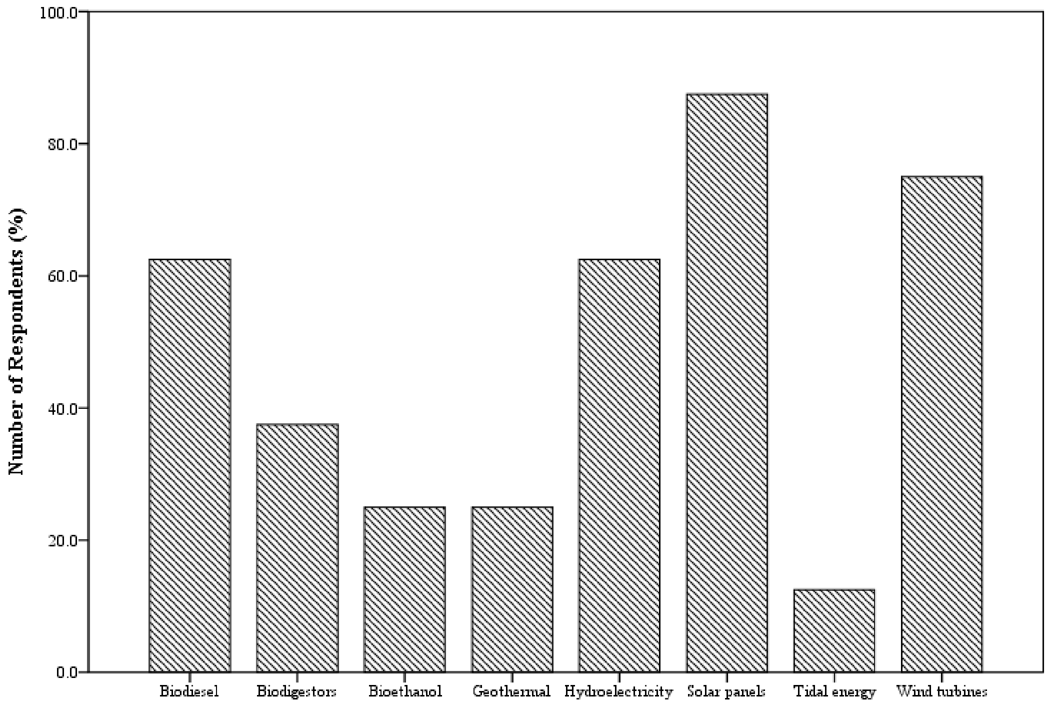


All the respondents were asked to identify low carbon energy sources from a given list. By doing so it allowed for the identification of technologies that respondents were aware of but may not have realised were renewable energy sources. Figure 4.4 shows the technologies respondents identified.

Solar panels were the mostly widely recognised technology with 87.5% *(n=7)* of respondents identifying them. Wind turbines *(75.0%, n=6)*, biodiesel *(62.5%, n=5)*, and hydroelectricity *(62.5%, n=5)* were also widely recognised as means of energy generation.

Bio-digesters were identified by only 37.5% *(n=3)* of respondents. Bioethanol and geothermal power were identified by 25.0% *(n=2)* of respondents respectively and a single respondent *(12.5%)* recognised tidal power.

Figure 4.4: Low carbon technologies used for energy generation recognised by respondents.



The respondents were provided with a brief overview of each of the technologies before they were asked to indicate which they believe (if any) would be of most benefit if used as a means of delivering modern energy services to their household or village.

All of the respondents *(100.0%, n=8)* indicated that they believed the use of solar panels would provide the most benefits. Biogas and hydroelectricity were also identified by 75.0% *(n=6)* and 50.0% *(n=4)* of respondents respectively. Bioethanol, geothermal and wind power were only believed to be of benefit by 12.5% *(n=1)* of respondents.

When asked why they had chosen the technology they had, the respondents who believed solar power would be of most benefit did so because there is plenty of sunlight and because the energy produced would be cheap for the user. One respondent also gave having seen this technology used in another village as a reason. Some of those who identified biogas did so because there is plenty of biomass available as a feedstock from livestock which goes to waste and could help cut costs. Similarly it was the abundance of water during monsoon season and in the surrounding areas given as reasons by respondents for selecting hydroelectricity as a beneficial way of generating energy.

Despite highlighting the energy sources they believed would provide most benefit, 75.0% *(n=6)* of respondents indicated that they had no preference towards one energy source over another. Those that had preference *(25.0%, n=2)* cited solar power as their preference, giving its perceived cheapness as their reason for choice.

Despite this lack of preference towards any one particular energy supply, all of the respondents believed that rural communities such as their own should be provided with renewable or sustainable alternative energy supplies. Furthermore 87.5% *(n=7)* of respondents indicated alternative energy sources should be used over current energy supplies. ‘Unreliable’ was the reason given by the 12.5% *(n=1)* of respondents who did not think these energy resources should be used over current means. Reasons given by those respondents who thought these alternatives should be used are that they believed they would provide a cleaner, more reliable and most notably a cheaper energy supply.

Respondents were asked a series of questions to see how cost affected their choice to switch from their current energy supply to an alternative low carbon one, depending on the benefits that could be gained from switching.

If the cost remained the same and it would be helping protect the local environment, 87.5% *(n=7)* of respondents were willing to switch. If switching meant a safer and more reliable supply at the same cost, 100.0% *(n=8)* of the respondents were willing to switch.

If switching meant paying slightly more than their current energy supply 25.0% *(n=2)* of respondents indicated that they would switch if it helped protect the local environment. Furthermore 25.0% *(n=2)* would switch if it meant a safer and more reliable supply.

Of the respondents who said they would switch to help protect the local environment when the price stayed the same, only 28.6% *(n=2)* would still switch when the price was slightly higher, whereas 71.4% *(n=5)* no longer would.

25.0% *(n=2)* of respondents who indicated that they would switch to an alternative energy supply if it was the same price but meant a safer more reliable supply would also switch if it meant paying slightly more for the same benefits. 75.0% *(n=6)* would not switch if it meant having to pay more.

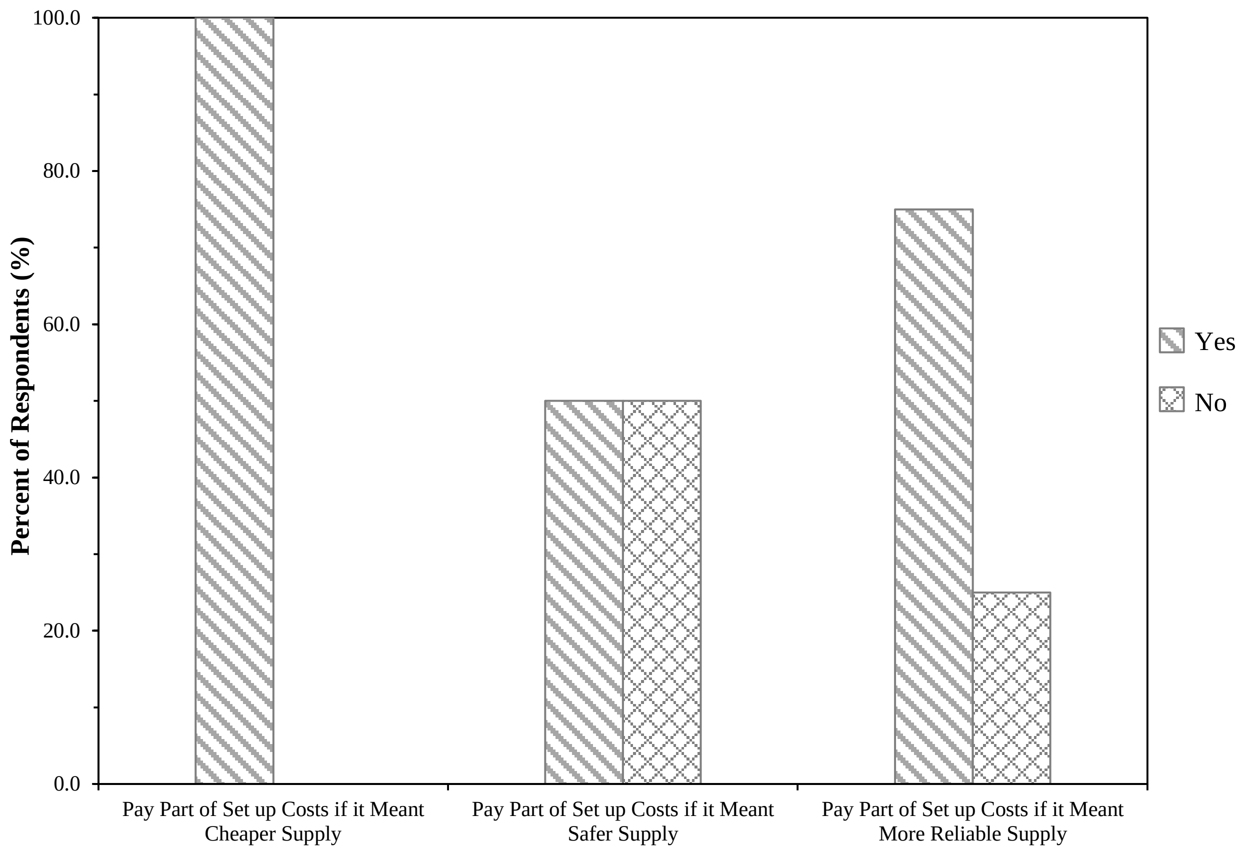
To establish what factors would influence a respondent’s choice to contribute towards the setup of a renewable or sustainable energy supply in their village, each was asked if they would contribute if it meant either a cheaper, more reliable or safer supply, see Figure 4.5.

100.0% *(n=8)* of respondents said they would contribute to the setup if it ultimately meant having a cheaper supply. For a safer supply, 50.0% *(n=4)* would contribute and 75.0% *(n=6)* would contribute for a more reliable supply.

Of the respondents who indicated that they would switch energy supply to an alternative if it was the same price as their current supply but also meant a safer and more reliable supply 75.0% *(n=6)* would also contribute to the set up costs for a more reliable supply, whereas only 50.0% *(n=4)* would contribute for a safer supply.

All of the respondents *(n=2)* who indicated that they would pay slightly more for a safer and more reliable supply also said they would contribute towards the setup of a renewable or sustainable energy source for these two benefits. Of the respondents that would not switch energy supplies if it meant paying slightly more, even if it meant a safer and more reliable supply, 33.3% *(n=2)* said they would contribute towards setup costs for a safer supply, and 66.7% *(n=4)* said they would contribute for a more reliable supply.

Figure 4.5: Factors affecting whether respondent would contribute to the cost of setting up a renewable or sustainable energy supply.



Respondents were asked to highlight any incentives that could be used to encourage them to adopt the use of renewable or sustainable energy supplies. Nearly all of the respondents *(87.5%, n=7)* identified reducing the overall costs of either the project or the energy supplies would be a significant incentive.

Several issues were highlighted by respondents as problems that could occur during the set-up and operation of an alternative renewable or sustainable energy supply that could threaten the success of a project.

Obstacles that respondents thought might be experienced during the set up included outsiders coming into the village *(12.5%, n=1)* and opposition towards an unfamiliar energy source *(25.0%, n=2)* particularly from older generations. 37.5% *(n=3)* of respondents also highlighted concerns around how expensive the set up might be which could potentially cause problems. A further 50.0% *(n=4)* of respondents could not think of any problems, although they did not specify that there would not be any problems.

The main problems that respondents thought might be experienced during the operation of an installed renewable or sustainable energy source centred around the on-going maintenance of the equipment *(37.5%, n=3)* and maintaining a reliable supply *(25.0%, n=2)* during periods when generation was not possible (e.g. solar power when cloudy). A further 25.0% *(n=2)* of respondents suggested that a lack of understanding on how the equipment worked could cause problems. Some respondents *(12.5%, n=1)* voiced concerns that the cost of the energy supplied would be too high making it unaffordable thus unavailable to many members of the community it is aimed at serving.

4.2.7. Archetypical Household From the Village of Uddhar

Based on the results of this survey a summary of a typical household from the village of Uddhar is as follows:

Household:

- Has 4 permanent occupants with the head of the household being male, who is not responsible for deciding what fuels are used in the household. Instead this is a shared responsibility.

- The household is a single storied building constructed using mud for the walls and flooring and tiles for the roofing. Consisting of 3 rooms with just a single covered entrance and 4 windows which are not left open.

- The household has 1 cow and uses 2.8 acres of land to grow rice crops.

Energy Usage:

- In the mornings non-natural lighting is used for 1.7 hours per day in the summer and 2.0 hours per day in the winter. In the evenings non-natural lighting is used for 4.4 hours per day during winter and 4.1 hours per day during the summer.

- Electricity is used as the main energy source for non-natural lighting in the household, with candles, paraffin/kerosene and firewood/biomass used as additional sources.

- Artificial lighting enables 1 person in the household to complete an additional 21.8 hours of productive work per week which contributes to the household income.

- Fuel lamps and electric light are used as a means of generating light with the household using 7 electric lights (4 fluorescent lights and 3 energy saving light bulbs (9 watt)) and 1 fuel lamp which consumes 0.72 litres per day.

- Electricity is available from the national or state grid.

- 4.4 hours per day is spent cooking, with one type of firewood or biomass being used as the main energy source and another as an alternative. 69.0 kg of firewood or biomass is utilised per month for household cooking.

- Electricity is used to power equipment to cool the household for 9.5 hours per day during the summer and 5.2 hours per day during the winter.

Amenities:

- Household owns a radio, television, telephone and mechanical fans.

Finances:

- The households total expenditure, excluding fuels, is 59.86 GBP per month. Broken down as 36.32 GBP per month on food, 4.23 GBP per month on transport, 13.48 GBP per month on education fees, 2.89 GBP per month on cloths, 2.94 GBP per month on health care.

- The household has a total income of 86.11 GBP per month. Two members of the household, 1 male and 1 female, are in paid employment which contributes to the household income. The male works 72.0 hours per week and earns 71.19 GBP per month and the female works 25.5 hours per week earning 14.92 GBP per month.

Fuel expenditure:

- The households total monthly fuel expenditure is 6.74 GBP per month, with 3.77 GBP spent per month on electricity and 2.97 GBP per month on firewood and biomass.
- An additional un-quantified volume of firewood and biomass is obtained for free from nearby forest of from livestock.
- Household Fuel usage decrease in the winter compared to the summer.

Use of non-work time:

- Female members of the household spend 10.0 hours per week on recreational activities. Male members of the household spend 24.7 hours per week in education, 11.1 hours per week on recreational activities

Statistical Analysis

4.2.8. Outcome vs. Categorical Independent

Table 4.11 presents the variables that came out as significant against the outcome variables from completing Fishers exact test.

Respondents who used steel as the main material for household roofing were more likely to pay slightly more for energy from a renewable or sustainable energy sources if they knew it was helping to protect the local environment.

Respondents who gave ‘easily available’ as a reason for using their primary fuel for household lighting were more likely to pay part of the set up costs for a renewable or sustainable energy supply if it meant a safer supply. In addition respondents who indicated using paraffin/kerosene for household cooking were less likely to pay part of the set up costs for a renewable or sustainable energy supply even if it meant a safer supply than those who did not use paraffin/kerosene for household cooking.

Respondents who used mud as the main material for the households roofing were less likely to pay part of the set up costs for a renewable or sustainable energy supply if it meant a more reliable supply than those who did not use mud as a roofing material.

In addition respondents who indicated that they ‘do not want’ a kettle were more likely to pay part of the set up costs for a renewable or sustainable energy supply if it meant a more reliable supply than those who already had a kettle.

Table 4.11: Fishers Exact Test summary of variables that were shown to have significant (<0.05) relationship to the outcome variable.

Variables		Sig
Outcome	Independent	
Pay Slightly more for energy from renewable/sustainable sources if helping protect local environment	Steel used as main material for roofing	0.036
Pay part of the set up costs for renewable/sustainable energy supply if meant a safer supply	Reason for using main fuel for household lighting: Easily available	0.029
	Paraffin/kerosene used for household cooking	0.029
Pay part of the set up costs for renewable/sustainable energy supply if meant a more reliable supply	Mud used as main material for roofing	0.036
	Kettle ownership	0.036

4.2.9. Outcome vs. Continuous Independent

Outcome variable: Do you think these types of energy [renewables] should be used over current means of energy provisions?

Table 4.12: Summary of significant continuous variables from linear discriminant analysis of the outcome variable: Do you think these types energy should be used over current means of energy provisions?

Independent Variables	Wilks' Lambda	Chi-square	Canonical Correlation	Sig
Number of windows in the house	0.286	6.890	0.845	<0.01
Total number of people in employment in household	0.429	4.660	0.756	0.031
Number of females in employment	0.429	4.660	0.756	0.031
Total number of people in household	0.357	5.663	0.802	0.017

Respondents were more likely to believe that renewable and sustainable types of energy should be used over current means of energy provisions relative to the number of windows they had in the household; the more windows, the more likely the respondent would say ‘yes’.

Furthermore households with a higher number of total people in paid employment as well as those with a higher number of female household members in employment were also more likely to say ‘yes’ to thinking renewable and sustainable types energy should be used over current means.

The size of the total household also effected this decision with respondents with a larger household more likely to say ‘yes’ than those with smaller numbers of people.

Outcome variable: If the cost of using these sources [renewables] was the same as your current supply would you consider switching over if you knew it was helping protect the local environment?

Only a single continuous variable was significant against this outcome variable (Table 4.13). Households with a higher female weekly income were less likely to switch energy sources even if it meant helping protect the local environment.

Table 4.13 Summary of significant continuous variables from linear discriminant analysis of the outcome variable: If the cost of using these sources was the same as your current supply would you consider switching over if you knew it was helping protect the local environment?

Independent Variables	Wilks’ Lambda	Chi-square	Canonical Correlation	Sig
Female weekly income	0.062	4.161	0.968	0.041

Outcome variable: Would you pay slightly more for energy from renewable or sustainable sources if you knew it was safer and more reliable?

Table 4.14: Summary of significant continuous variables from linear discriminant analysis of the outcome variable: Would you pay slightly more for energy from renewable or sustainable sources if you knew it was safer and more reliable?

Independent Variables	Wilks’ Lambda	Chi-square	Canonical Correlation	Sig
Monthly electricity expenditure	0.373	5.426	0.792	0.020

The higher the household’s monthly expenditure on electricity, the more likely the respondent was to be willing to pay slightly more for a renewable or sustainable energy source if they knew it meant a safer and more reliable supply.

Outcome variable: Would you pay part of the set up costs for a renewable or sustainable energy supply if it meant a safer supply?

Table 4.15: Summary of significant continuous variables from linear discriminant analysis of the outcome variable: Would you pay part of the set up costs for a renewable or sustainable energy supply if it meant a safer supply?

Independent Variables	Wilks' Lambda	Chi-square	Canonical Correlation	Sig
Total number of electrical lights	0.417	4.815	0.764	0.028
Number of years household has had access to electricity	0.335	6.021	0.816	0.014
Total household weekly income from employment	0.462	4.248	0.734	0.039
Male weekly income	0.430	4.639	0.755	0.031
Female weekly income	0.62	4.161	0.968	0.041
Monthly expenditure on transport	0.344	5.865	0.810	0.015

Households that had a higher number of electrical lights were less likely to want to pay towards the set up costs of a renewable or sustainable energy supply even if it meant a safer supply. The length of time a household has had access to electricity also affected a respondents choice to pay towards set costs for a safer supply; with those who have had access to electricity for the longest less likely to pay towards the set up costs.

Households with higher total weekly incomes as well as higher respective weekly incomes from males and females were also less likely pay towards the set up costs of a renewable or sustainable energy supply even if it meant a safer supply. In addition respondents from households with higher monthly transport expenditure were less likely to pay towards the set up costs.

Outcome variable: Would you pay part of the set up costs for a renewable or sustainable energy supply if it meant a more reliable supply?

Households with higher numbers of permanent occupants and people in the household were more likely to pay towards the set-up of a renewable or sustainable energy supply if it meant a more reliable supply. Respondents with more windows in their household were more likely to pay towards the set-up cost of a renewable or sustainable energy supply.

Table 4.16: Summary of significant continuous variables from linear discriminant analysis of the outcome variable: Would you pay part of the set up costs for a renewable or sustainable energy supply if it meant a more reliable supply?

Independent Variables	Wilks' Lambda	Chi-square	Canonical Correlation	Sig
Number of permanent occupants in household	0.444	4.460	0.754	0.035
Number of windows in the house	0.4	5.040	0.775	0.025
Number of years household has had access to electricity	0.488	3.947	0.716	0.047
Total number of people in household	0.333	6.042	0.816	0.014

Respondents were, however, less likely to consider paying towards the set up cost of a renewable or sustainable energy supply even if it meant a more reliable supply the longer the household had had access to electricity.

4.2.10. Additional Variable analysis

In addition to the statistical analyses carried out on the selected outcome variables from section 6 of the survey, variables that were significantly associated with independent variables that were significantly associated with these outcome variables were identified. In doing so this would help identify any 'hidden' factors which may be influencing the variables significantly associated with the outcome variables.

Fisher's Exact Test

Table 4.11 shows the categorical independent variables that were significantly associated with the outcome variables from section 6 of the survey. Table 4.17 shows the categorical variables that were significantly associated with these. The table shows that there were no other significant associations between the variables that were significantly associated with the outcome variables from section 6 and other variables; however, they were associated with one another.

Respondents who did not use mud as the main material for roofing were more likely to not want a kettle. The relationship between these two variables may just be coincidental as they were both shown to have a significant association with the outcome variable 'pay part of the set up costs for renewable/sustainable energy supply if meant a more reliable supply' (Table 4.11). These results could be reflecting this association rather than revealing any true relationship between these two variables

Respondents who used their main fuel for household cooking because it was 'easily available' were less likely to use paraffin/kerosene for household cooking. Respondents who did use paraffin/kerosene for household cooking were less likely to give 'easily available' as a reason for using the main fuel they did for household cooking. As with the previous set, these two variables were also shown to be significantly associated with the same outcome variable from section 6 of the survey 'Pay part of the set up costs for renewable/sustainable energy supply if meant a safer supply', see Table 4.11. The relationship between these two variables mirrors those under which respondents were more likely to pay part of the set up costs for a safer supply given their responses to these two variables.

Table 4.17: Fishers Exact Test summary of variables *(b)* that were shown to have significant (<0.05) relationship to the variable *(a)* previously shown to be significant associated with outcome variables from section 6 of survey.

Variables		Sig
a	*B*	
Mud used as main material for roofing	Kettle ownership	0.036
Reason for using main fuel for household lighting: Easily available	Paraffin/kerosene used for household cooking	0.029
Kettle ownership	Mud used as main material for roofing	0.036
Paraffin/kerosene used for household cooking	Reason for using main fuel for household lighting: Easily available	0.029

Pearson Correlation

Twelve continuous variables were shown to have a significant association with the outcome variable in section 6 (LDA), see Table 4.12-Table 4.16. Table 4.18 presents the continuous variables that had a significant association with these variables. Of the twenty-two unique variables *(b)* identified as having a significant association with one or more variables from column *a,* thirteen had no prior significant association with any of the outcome variables selected from section 6 of the survey. Furthermore, of the twelve significant associations identified between the variables that had previously been shown to be significantly associated with the outcome variables from section 6 through LDA, only four were found to be between variables that had not been associated with the same outcome variable in the LDA. These variables, along with those with no prior significant association with the outcome variables from section 6 of the survey are marked in the relevant column in Table 4.18.

The variable 'number of years household has had access to electricity' is excluded from column *a* of the table as no other variables where shown to be significantly associated with it.

Households with a larger number of permanent occupants were significantly more likely to have a higher number of people in employment, as well as significantly more females in employment. These household were also significantly more likely to have a higher number of windows in the household and were also, unsurprisingly, significantly more likely to have a larger number of people in the household

Households with a higher number of windows were also significantly more likely to be associated with households with a higher total number of people as well as a higher total number of permanent occupants.

There is a significant negative correlation between the number of electric lights used in a household and the number of people in employment. As the total number of electrical lights used increases, the number of people in employment decreases. There is also a significant negative correlation between the 'total number of electrical lights' and the 'total hours household spends in employment per week' and the 'number of females in employment'. In both cases as the number of electrical lights used increased, the total hours spent in employment and number of female in employment decreased.

Table 4.18: Pearson correlation summary of variables *(b)* that were shown to have significant (<0.05) relationship to the variable *(a)* previously shown to be significant associated with outcome variables from section 6 of survey.

Variables		Pearson's correlation	Sig
a	*b*		
Number of permanent occupants in household	Number of windows in the house	0.924	<0.01**
	Total number of people in employment in household§	0.775	0.024*
	Number of females in employment§	0.775	0.024*
	Total number of people in household	0.913	<0.01**
Number of windows in the house	Number of permanent occupants in household	0.924	<0.01**
	Total number of people in household	0.949	<0.01**
Total number of electrical lights	Total number of people in employment in household§	-0.764	0.027*
	Total hours household spends in employment per week#	-0.731	0.040*
	Number of females in employment§	-0.764	0.027*

Variables *a*	*b*	Pearson's correlation	Sig
Monthly electricity expenditure	Monthly expenditure on transport	0.901	<0.01**
	Monthly expenditure on education#	0.847	0.033*
	Number of hours non-natural lighting used in the morning during summer (per day)#	-0.806	0.029*
	Total household fuel expense per month#	0.902	<0.01**
	Male hours spent in education per week#	-0.917	0.028*
	Monthly expenditure on food#	0.910	<0.01**
Total number of people in employment in household	Number of permanent occupants in household§	0.775	0.024*
	Total number of electrical lights§	-0.764	0.027*
	Total hours household spends in employment per week#	0.758	0.029*
	Number of females in employment	1.000	<0.01**
	Total number of people in household	0.707	0.050*
	Total household monthly expenditure (excluding fuels)	0.883	<0.01**
Total household weekly income from employment	Male weekly income	0.925	<0.01**
	Total household income per month#	0.983	<0.01**
Number of females in employment	Number of permanent occupants in household§	0.775	0.024*
	Total number of electrical lights§	-0.764	0.027*
	Total number of people in employment in household	1.000	<0.01**
	Total hours household spends in employment per week#	0.758	0.029*
	Total number of people in household	0.707	0.050*
Male weekly income	Total household weekly income from employment	0.925	<0.01**
	Total household income per month#	0.884	<0.01**
Female weekly income	Number of entrances into the household#	0.968	0.032*
	Number of hours non-natural lighting used at night during summer (per day)#	0.968	0.032*
	Time spent cooking per 24 hours#	0.992	<0.01**
	Monthly expenditure on education#	-0.999	0.023*
	Monthly expenditure on healthcare#	0.968	0.032*
Total number of people in household	Number of permanent occupants in household	0.913	<0.01**
	Number of windows in the house	0.949	<0.01**
	Total number of people in employment in household	0.707	0.050*
	Number of females in employment	0.707	0.050*

Variables *a*	Variables *b*	Pearson's correlation	Sig
Monthly expenditure on transport	Total number of electrical lights	0.901	<0.01**
	Number of hours air conditioning used during summer per 24 hours#	0.857	<0.01**

#Variable with no prior significant association with outcome variables from section 6

§Variable not associated with same outcome variable from section 6 as variable in column *a*

*Correlation is significant at the 0.05 level

**Correlation is significant at the 0.01 level

There was a significant positive correlation between the 'total number of electrical lights' and the 'monthly expenditure on transport' and 'monthly expenditure on education'. In both cases as the total number of electrical lights used increased so did the monthly expenses on transport and education.

Four variables had a significant association with the variable 'monthly electricity expenditure'. Two of the variables, 'number of hours of non-natural lighting uses in the morning during the summer (per day)' and 'male hours spent in education per week', were negatively correlated. As the monthly electricity expenditure increased, the number of hours non-natural light is used in the morning during summer (per day) decreased, as did the number of hours male members of the household spent in education.

The variables 'total household fuel expense per month' and 'monthly expenditure on food' had significant positive correlations with the variable 'monthly electricity expenditure'; as the monthly electricity expenditure increased, as did the monthly total household fuel expense and the total monthly expenditure on food.

Six variables were significantly associated with the 'total number of people in employment in the household', of which five had a positive association including: the 'number of permanent occupants in household', 'total hours household spends in employment per week', 'number of females in employment', 'total number of people in household' and 'total household monthly expenditure (excluding fuels)', meaning that as the number of people in employment in each household increased so did the number of permanent occupants, total hours per week spent in employment by household, number of females in employment, total of number of people in household and the total monthly expenditure (excluding fuels).

The variable ‘total number of electrical lights’ had a negative significant association with the total number of people in employment in a household.

‘Total household weekly income from employment’ had two significant positive associations’. These two variables were ‘male weekly income’ and ‘total household income per month’.

Five variables were significantly associated with the ‘number of females in employment’. ‘Total number of electrical lights’ was the only variable with a negative association. The variables, ‘number of permanent occupants in household’, ‘total number of people in employment in household’, ‘total hours household spends in employment per week’, and ‘total number of people in household’ all had positive correlations with the number of females in employment.

‘Male weekly income’ was significantly positively correlated with the ‘total household weekly income from employment’ and the ‘total household income per month’.

The variable ‘female weekly income’ was significantly associated with 5 variables; ‘number of entrances into household’, ‘number of hours non-natural lighting is used at night during summer (per day)’, ‘time spent cooking per 24 hours’, ‘monthly expenditure on education’, ‘monthly expenditure on healthcare’. All of these variables had a positive correlation with the dependent variable (‘female weekly income’) except for ‘monthly expenditure on education’ for which a negative correlation was observed.

Four variables were found to have significant positive associations with the variable ‘total number of people in household’. These variables include ‘number of permanent occupants in household’, ‘number of windows in the house’, ‘total number of people in employment in household’, and ‘number of females in employment’.

The variable ‘monthly expenditure on transport’ had two significant positive associations with the variables ‘total number of electrical lights’ and ‘number of hours air conditioning used during summer per 24 hours’.

Analysis Of Variance

Analysis of variance was carried out to look for categorical variables with significant associations with the twelve continuous variables that were shown to be significantly associated with the outcome variables selected from section 6 of the survey through LDA. The results of this are summarised in Table 4.19.

Of the fifty-two unique variables *(b)* identified as having a significant association with one or more variables from column *a*, forty-eight had no prior significant association with any of the outcome variables selected from section 6 of the survey.

None of the independent variables (*b*) were found to be significantly associated with the same outcome variable selected from section 6 of the survey as the outcome variables from the ANOVA analysis (*a*). However, the independent variables (*b*) that had previously been shown to be significantly associated with the same outcome variables from section 6 of the survey through Fisher's Exact Test (Table 4.11) were also found to be significantly associated with one or more of the same outcome variables used in the ANOVA analysis (*a*).

Table 4.19: Summary of analysis of variance of variables *(b)* that were shown to have significant (<0.05) relationship to the variable *(a)* previously shown to be significant associated with outcome variables from section 6 of survey.

Variables *a*	*b*	DF	F value	Sig
Number of permanent occupants in household	Tiles used as main material for roofing#	1, 6	13.36	0.011*
	Mud used as main material for roofing	1, 6	7.89	0.031*
	Bricks used as main material for walls#	1, 6	13.36	0.011*
	Mud used as main material for walls#	1, 6	13.02	0.011*
	Candles available for cooking but not used#	1, 6	22.53	<0.01**
	Kettle ownership	1, 6	7.89	0.031*
	Freezer ownership#	2, 4	7.60	0.043*
	Biogas would be a beneficial energy supply#	1, 6	7.89	0.031*
Number of windows in the house	Mud used as main material for roofing	1, 6	9.00	0.024*
	Other energy sources for lighting used during power cuts#	1, 6	15.00	<0.01**
	Firewood/biomass available for household lighting but not used#	1, 6	15.00	<0.01**
	Candles available for cooking but not used#	1, 6	11.31	0.015*
	Kettle ownership	1, 6	9.00	0.024*
	Identified solar power as example of renewable/sustainable energy#	1, 6	15.00	<0.01**
	Biogas would be a beneficial energy supply#	1, 6	9.00	0.024*
Total number of electrical lights	Are windows in household always open#	1, 6	6.95	0.039*
	Reason for using main fuel for household lighting: Easily available	1, 6	8.40	0.027*
	Paraffin/kerosene used for household cooking	1, 6	8.40	0.027*
	Identified biodiesel as example of renewable/sustainable energy#	1, 6	8.00	0.030*
	Has heard of bio-digesters/biogas#	1, 6	15.00	<0.01**

Variables *a*	Variables *b*	DF	F value	Sig
Number of years household has had access to electricity	Do you grow your own crops#	1, 6	6.64	0.042*
	Mud used as main material for roofing	1, 6	6.30	0.046*
	Reason for using main fuel for household lighting: Easily available	1, 6	11.93	0.014*
	Unhappy with main fuel for lighting because: Unreliable#	1, 6	6.30	0.046*
	Reason for using main fuel for household cooking: Familiar fuel#	1, 6	11.93	0.014*
	Unhappy with main fuel for cooking because: Expensive#	1, 6	6.30	0.046*
	Paraffin/kerosene used for household cooking	1, 6	11.93	0.014*
	Kettle ownership	1, 6	6.30	0.046*
Monthly electricity expenditure	Do you keep livestock#	1, 6	83.36	<0.01**
	Firewood/biomass available for household cooking but not used#	1, 6	83.36	<0.01**
	Batteries used to supply electricity to household#	1, 6	83.36	<0.01**
	Has heard of tidal energy#	1, 6	83.36	<0.01**
	Bioethanol would be a beneficial energy supply#	1, 6	83.36	<0.01**
	Geothermal power would be a beneficial energy supply#	1, 6	83.36	<0.01**
	Wind power would be a beneficial energy supply#	1, 6	83.36	<0.01**
Total number of people in employment in household	Unhappy with main fuel for lighting because: Unreliable#	1, 5	9.29	0.029*
	Filament bulbs used for household lighting#	1, 5	8.93	0.031*
	Fluorescent lights used for household lighting#	1, 5	8.93	0.031*
	Unhappy with main fuel for cooking because: Expensive#	1, 5	9.29	0.029*
	Oven ownership#	2, 4	7.29	0.046*
	Any other source of household income#	1, 6	8.00	0.030*
	Identified solar power as example of renewable/sustainable energy#	1, 6	8.00	0.030*
	Has heard of Solar panels#	1, 6	8.00	0.030*
Total household weekly income from employment	Reason for using main fuel for household lighting: Easily available	1, 6	6.99	0.038*
	Paraffin/kerosene used for household cooking	1, 6	6.99	0.038*
	Firewood/biomass used for household cooking#	1, 6	8.15	0.029*
	Paraffin/kerosene available for household cooking but not used#	1, 6	10.45	0.018*
	Monthly fuel expenditure includes Kerosene#	1, 6	20.34	<0.01**
	Do you buy all the fuel you use#	1, 6	20.34	<0.01**
	Refrigerator ownership#	1, 6	8.15	0.029*

Variables *a*	*b*	DF	F value	Sig
	Identified bioethanol as example of renewable/sustainable energy#	1, 6	20.34	<0.01**
	Has heard of biodiesel#	1, 6	10.45	0.018*
	Do you have a preferred energy source#	1, 6	8.15	0.029*
Number of females in employment	Candles used as alternative energy source for household lighting#	1, 6	8.00	0.030*
	Other energy sources for lighting used during power cuts#	1, 6	8.00	0.030*
	Firewood/biomass available for household lighting but not used#	1, 6	8.00	0.030*
	No other source used for household cooking#	1, 6	8.00	0.030*
	LPG used for household cooking#	1, 6	8.00	0.030*
	Is equipment used for cooling powered by electricity#	1, 6	8.00	0.030*
	Any other source of household income#	1, 6	8.00	0.030*
	Identified solar power as example of renewable/sustainable energy#	1, 6	8.00	0.030*
	Has heard of Solar panels#	1, 6	8.00	0.030*
Male weekly income	Do you grow your own crops#	1, 6	8.50	0.027*
	Reason for using main fuel for household lighting: Easily available	1, 6	7.95	0.030*
	Unhappy with main fuel for lighting because: Unreliable#	1, 6	7.58	0.033*
	Unhappy with main fuel for cooking because: Expensive#	1, 6	7.58	0.033*
	Paraffin/kerosene used for household cooking	1, 6	7.95	0.030*
	Paraffin/kerosene available for household cooking but not used#	1, 6	8.50	0.027*
	Monthly fuel expenditure includes Kerosene#	1, 6	7.95	0.030*
	Do you buy all the fuels you use#	1, 6	7.95	0.030*
	Identified bioethanol as example of renewable/sustainable energy#	1, 6	7.95	0.030*
	Has heard of biodiesel#	1, 6	8.50	0.027*
Female weekly income	Do you grow your own crops#	1, 2	30.04	0.032*
	Cement used as main material for roofing#	1, 2	30.04	0.032*
	Wood used as main material for walls#	1, 2	30.04	0.032*
	Tiles used as main material for flooring#	1, 2	30.04	0.032*
	Mud used as main material for flooring#	1, 2	30.04	0.032*
	Reason for using main fuel for household lighting: Easily available	1, 2	30.04	0.032*
	Paraffin/kerosene used as alternative energy source for household lighting#	1, 2	30.04	0.032*

Variables a	Variables b	DF	F value	Sig
Female weekly income (cont)	Reason LPG not used for household lighting: Expensive#	1, 2	30.04	0.032*
	Monthly household expenditure includes Education fees#	1, 2	30.04	0.032*
	Do you have a preferred renewable/sustainable energy source#	1, 2	30.04	0.032*
Total number of people in household	Unhappy with main fuel for lighting because: Unreliable#	1, 5	9.29	0.029*
	Filament bulbs used for household lighting#	1, 5	8.93	0.031*
	Fluorescent lights used for household lighting#	1, 5	8.93	0.031*
	Unhappy with main fuel for cooking because: Expensive#	1, 5	9.29	0.029*
	Oven ownership#	2, 4	7.29	0.046*
	Identified solar power as example of renewable/sustainable energy#	1, 6	10.80	0.017*
	Biogas would be a beneficial energy supply#	1, 6	12.00	0.013*
Monthly expenditure on transport	Respondents age#	3, 4	7.06	0.045*
	Reason for using main fuel for household lighting: Easily available	1, 6	11.43	0.015*
	Fluorescent lights used for household lighting#	1, 6	6.13	0.048*
	Paraffin/kerosene used for household cooking	1, 6	11.43	0.015*
	Firewood/biomass used for household cooking#	1, 6	9.12	0.023*
	Refrigerator ownership#	1, 6	9.12	0.023*
	Freezer ownership#	2, 4	11.14	0.023*
	Has heard of bio-digesters/biogas#	1, 6	8.68	0.026*
	Do you have a preferred energy source#	1, 6	9.12	0.023*

#Variable with no prior significant association with outcome variables from section 6

*Correlation is significant at the 0.05 level

**Correlation is significant at the 0.01 level

The 'number of permanent occupants in the household' was significantly associated with eight variables using ANOVA including: 'tiles used as main material for roofing', 'mud used as main material for roofing', 'bricks used as main material for walls', 'mud used as main material for walls', 'candles available for cooking but not used', 'kettle ownership', 'freezer ownership', and 'biogas would be a beneficial energy supply'

Seven variables were found to be significantly associated with the variable 'number of windows in the house'. These were the variables 'mud used as main material for roofing', 'other energy sources for lighting used during power cuts', 'firewood/biomass available for household lighting but not used', 'candles available for cooking but not used', 'kettle ownership', 'identified solar power as example of renewable/sustainable energy', and 'biogas would be a beneficial energy supply'.

The variable 'total number of electrical lights' was found to have significant associations with five categorical variables, 'are windows in household always open', 'reason for using main fuel for household lighting: Easily available', 'paraffin/kerosene used for household cooking', 'identified biodiesel as example of renewable/sustainable energy', and 'has heard of bio-digesters/biogas'.

Eights variables were found to be significantly associated with the variable 'number of years household has had access to electricity' including: 'do you grow your own crops', 'mud used as main material for roofing', 'reason for using main fuel for household lighting: Easily available', 'unhappy with main fuel for lighting because: Unreliable', 'reason for using main fuel for household cooking: Familiar fuel', 'unhappy with main fuel for cooking because: Expensive', 'paraffin/kerosene used for household cooking', and 'kettle ownership'.

The variable 'monthly electricity expenditure' was found to have significant associations with seven variables, 'do you keep livestock', 'firewood/biomass available for household cooking but not used', 'batteries used to supply electricity to household', 'has heard of tidal energy', 'bioethanol would be a beneficial energy supply', 'geothermal power would be a beneficial energy supply', and 'wind power would be a beneficial energy supply'.

Significantly associations were found between the variable 'total number of people in employment in household' and the variables 'unhappy with main fuel for lighting because: Unreliable', 'filament bulbs used for household lighting', 'fluorescent lights used for household lighting', 'unhappy with main fuel for cooking because: Expensive', 'oven ownership', 'any other source of household income', 'identified solar power as example of renewable/sustainable energy', and 'has heard of Solar panels'.

Ten variables were found to have significant associations with the variable 'total household weekly income from employment', 'reason for using main fuel for household lighting: Easily available', 'paraffin/kerosene used for household cooking', 'firewood/biomass used for household cooking', 'paraffin/kerosene available for household cooking but not used', 'monthly fuel expenditure includes Kerosene', 'do you buy all the fuel you use', 'refrigerator ownership', 'identified bioethanol as example of renewable/sustainable energy', 'has heard of biodiesel', and 'do you have a preferred energy source'.

The variables 'candles used as alternative energy source for household lighting', 'other energy sources for lighting used during power cuts', 'firewood/biomass available for household lighting but not used', 'no other source used for household cooking', 'LPG used for household cooking', 'is equipment used for cooling powered by electricity', 'any other source of household income', 'identified solar power as example of renewable/sustainable energy', and 'has heard of Solar panels', were all found to be significantly associated with the variable 'number of females in employment'.

'Male weekly income' was significantly associated with the variables 'do you grow your own crops', 'reason for using main fuel for household lighting: Easily available', 'unhappy with main fuel for lighting because: Unreliable', 'unhappy with main fuel for cooking because: Expensive', 'paraffin/kerosene used for household cooking', 'paraffin/kerosene available for household cooking but not used', 'monthly fuel expenditure includes Kerosene', 'do you buy all the fuels you use', 'identified bioethanol as example of renewable/sustainable energy', and 'has heard of biodiesel'.

'Female weekly income' was significantly associated with ten variables. These variables were 'do you grow your own crops', 'cement used as main material for roofing', 'wood used as main material for walls', 'tiles used as main material for flooring', 'mud used as main material for flooring', 'reason for using main fuel for household lighting: Easily available', 'paraffin/kerosene used as alternative energy source for household lighting', 'reason LPG not used for household lighting: Expensive', 'monthly household expenditure includes Education fees', and 'do you have a preferred renewable/sustainable energy source'.

The variable 'total number of people in household' had seven significant associations with the variables 'unhappy with main fuel for lighting because: Unreliable', 'filament bulbs used for household lighting', 'fluorescent lights used for household lighting', 'unhappy with main fuel for cooking because: Expensive', 'oven ownership', 'identified solar power as example of renewable/sustainable energy', and 'biogas would be a beneficial energy supply'.

Nine variables were significantly associated with the variable 'monthly expenditure on transport'. These were 'respondents age', 'reason for using main fuel for household lighting: Easily available', 'fluorescent lights used for household lighting', 'paraffin/kerosene used for household cooking', 'firewood/biomass used for household cooking', 'refrigerator ownership', 'freezer ownership', 'has heard of bio-digesters/biogas', and 'do you have a preferred energy source'.

Linear Discriminant Analysis

Linear discriminant analysis was carried out on the five categorical variables that were found to be significantly associated with the outcome variables selected from section 6 of the survey as a result of fisher's exact test (Table 4.11). One variable ('steel used as main material for roofing') was dropped as no additional continuous variables were found to be significantly associated with it after LDA.

Ten unique variables *(b)* were identified as having a significant association with one or more variable from column *a,* all of which had previously been identified as having significant association with one or more of the outcome variables selected from section 6 of the survey (see Tables 4.12 through 4.16). In addition the variables (*b*) that were found to be significantly associated with the same outcome variable from section 6 of the survey through Fisher's Exact Test (Table 4.11) were also found to be significantly associated with one or more of the same outcome variables used in the linear discriminant analysis (*a*).

All of the independent variables (*b*) were also found to be significantly associated with the same outcome variable from section 6 of the survey as one or more of the LDA outcome variables (*a*) that they were found have a significant association with.

The variable 'mud used as main material for roofing' was significantly associated with four variables, 'number of permanent occupants in household', 'number of windows in household', 'number of years household has had access to electricity', 'total number of people in household'.

Significantly associations were found between the variable 'reason for using main fuel for household lighting: Easily available' and the variables 'total number of electrical lights', 'number of years household has had access to electricity', 'total household weekly income from employment', 'male weekly income', 'female weekly income', 'monthly expenditure on transport'.

'Paraffin/kerosene used for household cooking' was significantly associated with six variables. These variables were 'total number of electrical lights, 'number of years household has had access to electricity', 'total household weekly income from employment', 'male weekly income', 'female weekly income', 'monthly expenditure on transport'.

The variable 'kettle ownership' was significantly associated with the variables, 'number of permanent occupants in household', 'number of windows in the household', 'number of years household has had access to electricity', 'total number of people in household'.

Table 4.20: Summary of linear discriminant analysis of variables (*b*) that were shown to have significant (<0.05) relationship to the variable (*a*) previously shown to be significant associated with outcome variables from section 6 of survey.

Variables *a*	*b*	Wilks' Lambda	Chi-square	Canonical correlation	Sig
Mud used as main material for roofing	Number of permanent occupants in household	0.444	4.460	0.754	0.035*
	Number of windows in the household	0.400	5.040	0.775	0.025*
	Number of years household has had access to electricity	0.488	3.947	0.716	0.047*
	Total number of people in household	0.333	6.042	0.816	0.014*
Reason for using main fuel for household lighting: Easily available	Total number of electrical lights	0.417	4.815	0.764	0.028*
	Number of years household has had access to electricity	0.335	6.021	0.816	0.014*
	Total household weekly income from employment	0.462	4.248	0.734	0.039*
	Male weekly income	0.430	4.639	0.755	0.031*
	Female weekly income	0.062	4.161	0.968	0.041*
	Monthly expenditure on transport	0.344	5.865	0.810	0.015*
Paraffin/kerosene used for household cooking	Total number of electrical lights	0.417	4.815	0.764	0.028*
	Number of years household has had access to electricity	0.335	6.021	0.816	0.014*
	Total household weekly income from employment	0.462	4.248	0.734	0.039*
	Male weekly income	0.430	4.639	0.755	0.031*
	Female weekly income	0.062	4.161	0.968	0.041*
	Monthly expenditure on transport	0.344	5.865	0.810	0.015*
Kettle ownership	Number of permanent occupants in household	0.444	4.460	0.745	0.035*
	Number of windows in the household	0.400	5.040	0.775	0.025*
	Number of years household has had access to electricity	0.488	3.947	0.716	0.047*
	Total number of people in household	0.333	6.042	0.816	0.014*

*Correlation is significant at the 0.05 level

4.3. Discussion

4.3.1. Descriptive Analysis Findings

Use of Fuels in the Home

All of the respondents in this study used electricity, mainly due to its ease of use and accessibility. All respondents were, however, unhappy with using electricity as their primary lighting fuel because it was expensive and unreliable and made use of an additional energy source also. Many respondents used an alternative energy supply for lighting during power cuts. However, more respondents considered the expense of electricity rather than the unreliability to be the main reason for being unhappy with this source. This could be because power cuts are expected when using electricity, and does not cause respondents to feel that this supply is particularly unreliable.

The Western world would consider electricity to be one of the most reliable sources of energy. However, the Indian electricity sector consistently has been peak shortages over 10% and has been troubled by black outs most notably during 2012 when 620 million people were affected for two days (Shukla *et al.* 2009). With this background, it becomes clear as to why there is a choice to rely on a primary and secondary source of energy for the lighting of homes in rural India. The high costs associated with using electricity paired with the aforementioned reliability issues force the residents of rural villages to have a backup option in this regard.

The most popular fuels used for household cooking were a combination of LP Gas and firewood or biomass. This is a mixture of traditional and modern energy supplies. The reasons why respondents chose each of these sources and the reasons why respondents may be unhappy with these sources are very different.

Many respondents were unhappy with firewood and biomass because it was 'too smoky'. The level of smoke produced by firewood/biomass is an identified health risk and is a valid concern of the respondents. The average distribution of particles arising from biomass in Indian household is 2000μg m^{-3} (Smith 2000) which is far in excess of the 150μg m^{-3} level set by the US Environmental Protection Agency (IEA 2007). When expanded to consider villages and areas of domestic living, localised pollution can occur during peak cooking times. As a result, acute respiratory infections are now the largest single disease category in India (IEA 2007). Reducing this level of pollution by using RETs would have benefits in terms of health as well as modern energy services.

Due to the opposing positive and negative aspects of firewood/biomass and LP gas, respondents would switch between these as primary and secondary sources of fuel. The expense associated with using LP Gas compared to the cheapness of using firewood or biomass might mean that when the LP Gas supply become too expensive or disrupted users switch to the cheaper, more familiar firewood or biomass. Balachandra (Balachandra 2011a) and Pohekar et al., (Pohekar *et al.* 2005) showed that the use of LP Gas as a primary fuel for household cooking was limited to high income household in rural areas which would support the idea those who use firewood or biomass, but also make use LP Gas, do so but only in specific circumstances as its high cost prevents continuous use.

Balachandra's (Balachandra 2011a) work however presents stark differences in comparison to the findings of this study for the proportion of households using LP Gas or firewood or biomass as their primary fuel for household cooking. Balachandra found that 84.1% of households made use of firewood or biomass, and only 8.6% of LP Gas for household cooking. This disparity can be put down to the fact Balachandra's analysis is based upon national statistics whereas this study explores the energy usage of one village.

Respondents' fuel usage was lower in the winter than in the summer, and the time respondents spent cooling their houses was lower in winter than in summer. This is most likely because they do not need to cool their houses to the same extent as in the summer periods. Average temperatures in the state of Maharashtra have a range of 24.1˚C, from as high as 38.6˚C in the summer to 14.5˚C in the winter (Lal 2005).

Fossil fuels were used by 87.5% of respondents as either their primary or alternative fuel for cooking. This is comparable to the global share fossil fuels represent for primary energy consumption which is also 87.0% (OPEC 2011). This comparison, however, is not reflected in the share of fuels used for lighting where 100.0% *of* the respondents made use of electricity derived from fossil fuel sources.

None of the respondents indicated that they were happy with the fuels they currently used primarily for household cooking or lighting, citing reasons mainly centred on ease of use, cost and reliability. The reasons given by respondents for being unhappy when using LP Gas and/or electricity are similar, as are the reasons the same respondents gave for using these two fuels. This is interesting as these two fuels are considered to be forms of modern energy (Balachandra 2011a), but despite being very different resources, the reasons for using them and the issues respondents had with them are the same, which would indicate that there are common issues experienced with the acquisition and use of modern energies in these communities.

The results highlight that ‘availability’ is an important factor when selecting fuels for household tasks. Although only a small number of the respondents gave it as a reason in each separate question, a more in depth look at the results shows that 75% of respondents selected availability as a reason for their choice in using one or more fuels. In addition it was the only reason to be selected as an influencing factor across all fuels used in household lighting and cooking. Accessibility has been highlighted by several studies (Painuly 2001, Reddy & Painuly 2004) to be a major barrier for modern energy access and in particular to the uptake of RETs. As these technologies have however been shown to lend themselves to being used as decentralised energy resources (Chakrabarti & Chakrabarti 2002, Hiremath *et al.* 2009, Mahapatra & Dasappa 2012) this can remove some of the accessibility barriers as the energy generation can be put at the heart of the community. Thiam (2010) and Chakrabarti & Chakrabarti (2002) note that as these technologies can be installed close to the point of demand the costs relating to energy transport and distribution are reduced which will ultimately lower the cost to the end user.

The reasons ‘cost’ and ‘easy to use’ were also important factors for choosing particular fuels. However, these were never given simultaneously for choosing a fuel. For example, all the respondents who used firewood or biomass for cooking indicated that the reason for using this fuel was that it was cheap. However, none of them gave ‘easy to use’ as a reason. Conversely, none of the respondents who selected electricity or LP Gas indicated ‘cheap’ as a reason for choosing this fuel, but ‘easy to use’ was by far the most significant influencing factor. An explanation for this is that the ease of using a specific fuel is offset by an increased cost.

From these results it could therefore be reasoned that there is a direct relationship between the cost of a fuel and how easy it is to use. Of these two factors ease of use is the most significant in terms of what is desired by the user. The results indicate that people appear willing to pay more for an energy resource which is easy to use, such as electricity or LP Gas, despite the expense which they highlight as their main dissatisfaction when using them. This supports the DFIDs (DFID 2002b) theory that it is the benefits of an energy source, of which ease of use is one, that ultimately drive demand as these are the factors people desire over energy access itself.

If cost alone was the overriding factor influencing which fuels were chosen for household activities, the easy to use but expensive fuels would not be selected to the same degree that they were. Cost appears to be the principal limiting factor on fuel selection, as although people desire a fuel that is easy to use, they may be unable to afford those that are available. This is most likely the case with the respondents who primarily use firewood or biomass for cooking as all of them indicated that they selected this resource because it was cheap, not because it was easy to use. This, in conjunction with the fact that the majority of these respondents indicated that they also make use of LP Gas as a secondary fuel, supports the idea that if cost was removed as a factor, the majority of respondents would prefer a fuel that was easy to use.

Perception, Attitudes & Barriers Towards Renewable Or Sustainable Energy Sources

The respondents were able to identify several low carbon energy sources from a given list. However, respondents although aware of fuels, were unaware of how they could be obtained. For example, despite all respondents having indicated using firewood or biomass as a primary or secondary fuel for household cooking, and many giving biogas as an example of a renewable energy resource, only 37.5% of respondents were aware of bio-digesters.

Lack of knowledge is the primary barrier to the adoption of any new technology. Lack of technical knowledge and awareness in RETs has been identified as a potential barrier to their uptake (Del Río 2007, Reddy & Painuly 2004). This may help explain why bio digesters became one of the preferred technologies after explanations were given, despite its low initial level of identification.

A lack of knowledge and understanding of the technologies available (as shown in the disparity between the LCT recognised and those which respondents thought would be a beneficial source of modern energy) and of the benefits and impacts associated with them, would explain why respondents were unable to identify a clear preference towards one energy source over another. Despite this, all of the respondents believed that rural communities, such as their own, should be provided with renewable or sustainable energy supplies. Furthermore many respondents indicated alternative energy sources should be used over current supplies.

Several studies (Moomow *et al.* 2011, Painuly 2001) have already highlighted acceptance as a vital factor in the implementation of RETs. Without it the likelihood of a successful project is reduced. This can damage the perception of RETs further, resulting in additional barriers to any future projects. Moomow *et al.* highlights that in many cases overcoming these barriers can be achieved by establishing dedicated lines of communication between planner and stakeholders from an early stage of planning. By incorporating public participation into planning decisions and by educating the target population of the long and short term benefits of using such technologies for energy generation should greatly improve their acceptance and successful implementation.

It is clear from the results exploring how cost affects a respondent's choice to switch to a low carbon energy supply that cost is the biggest barrier to the implementation of RETs in rural Indian villages. It is however important to understand what the underlying influential factors could be once the use of cost has been mitigated. The results indicate that out of reliability and safety, the latter is of least importance to the respondents, because when given the option respondents were willing to contribute a 'one-off' payment for improved reliability even though they would not pay long term for it, but would not do the same for improved safety.

As with selecting a fuel resource to use for household activities cost was the principal factor to influence a respondent's choice to switch to an alternative renewable or sustainable supply or contribute towards their set up costs.

The benefits of switching, such as reduced environmental impacts, reliability and safety, are insufficient on their own to persuade a respondent to switch. When cost is not a factor, when the energy resource price stays the same, respondents are more likely to be swayed to switch by these benefits. The desire for reducing the long term costs of energy provision were shown by the fact that all of respondents were willing to contribute to set up costs of a supply if ultimately it led to a cheaper supply.

The importance of cost was further emphasised as respondents indicated that a significant incentive which would encourage them to use renewable or sustainable energy supplies would be if it reduced the overall costs of energy consumption, furthermore the costs of setting up and the final cost of the energy supplied from these renewable or sustainable energy sources were highlighted as problems by respondents which might be experience during the set up and operation of these energy sources and could threaten their success.

Reliability was also shown to be an important factor that influenced a respondent's decision to switch to an alternative energy supply or contribute towards set up costs. It is a property that is desired in an energy supply, much like ease of use, and although not as significant as cost, respondents were more likely to pay in order to access an energy supply with this characteristic. This indicates that respondents were considering the long term benefits over the short term costs. As a reliable energy supply would reduce the need for alternatives, reducing energy expenditure, which combined with an affordable supply, will increase disposable income which could be used to improve other areas of day to day life.

Del Río (Del Río 2007) and Painuly (Painuly 2001) both identify that a lack of technical knowledge and skilled personnel for setting up and operating RETs in developing countries can affect their long term success and can lead to performance issues. With reliability being an important factor this is an important barrier which must be overcome if the introduction of RETs is to be successful and not lead to negative attitudes.

The high costs associated to RETs are one of the major barriers to their successful implementation. Gurung et al (Gurung *et al.* 2011), Painuly (Painuly 2001) and Reddy & Painuly (Reddy & Painuly 2004) highlight that high costs can often restrict access to these technologies as they become unaffordable solutions for energy provision. The need to improve infrastructure in many developing countries adds additional costs to RET projects. These costs may well be passed onto the consumer which can lead to problems of uptake when the costs start to exceed those in comparison to more conventional means of energy provision. This is reflected in the survey results where the costs of different energy resources are shown to play a significant role in the selection and extent of which a fuel is used.

Increased uncertainties and a lack of confidence can contribute to increased project costs and threaten the long term viability of a project (Mitchell *et al.* 2011, Painuly 2001). Painuly (Painuly 2001) and Reddy & Painuly (Reddy & Painuly 2004) both note that these elements can make attracting funding from financial and private investors difficult as they are often reluctant to provide funding for small scale projects that are associated with such risk. This can therefore make it almost impossible for people on low incomes to invest in RETs.

In addition the need to invest heavily in technical expertise and infrastructure, particularly in rural areas, can deter investors often leaving these areas isolated from sustainable development. However by evaluating the needs and attitudes of target communities many barriers can be overcome by using the appropriate energy resource to meet their needs, and by communicating with stakeholders from an early point.

The results show that there is interest in the use of sustainable or renewable energy sources over more traditional methods. This however must come in the form of an affordable, reliable and easy to use energy resource as these characteristic were highlighted by the respondents as the most influential drivers switching. They also represent two of the three main factors the UN AGECC highlight in their definition of energy access. The third factor (a clean energy source) although fulfilled by RETs seems of less importance to the respondents as the environmental benefits gained by using RETs are less influential when it comes to choosing an energy supply, the primary influencing factor has been demonstrated as being the cost of the energy supply.

4.3.2. Statistical Associations Explored

Outcome Variable: Do you think these types energy should be used over current means of energy provisions?

The variable 'do you think these types energy should be used over current means of energy provisions?' had four significant associations which could potentially be used as indicators of whether a respondent is likely to want renewable energy sources over current means of energy provisions. Those respondents who indicated that renewable and sustainable means of energy provision should be used over their current means of energy provision tended to have:

- A larger number of people in the household.
- A higher total number of people in employment.
- A greater number of female household members in employment.
- Live in larger houses, as indicated by having a high number windows' in the house.

These associations may be the result of several factors. Having a larger number of people in the household will increase the demand for energy. This may result in people considering other energy resource options, especially if they are unhappy with their current supplies. The 'total number of people in household' was significantly associated with whether a respondent was 'unhappy with main fuel for lighting because: unreliable' and 'unhappy with main fuel for cooking because: expensive'. As a result of being unable to meet their current energy requirements with the resources available, respondents may support the move to use alterative renewable energy resources.

People who are in employment may be able to interact with a variety of different people, and so even with limited education may be exposed to information and ideas and thus be more aware of the options renewable energy sources offer. Households with a higher total number of people in employment will correspond to households with a higher number of total occupants; in fact the two variables were shown to be significantly associated. It could be that the same factors which are influencing those respondents from households with a larger total number of occupants might well be the actual reasons for why those from household with a higher number of people in employment are in favour of using renewables over current means. The fact that the people are employed may be an additional factor that may not have any bearing at all; more people may have to work in the household in order to meet their basic energy needs. This is supported by the fact that these two variables were also found to share significant correlation with several of the same variables.

A similar conclusion may be drawn from the observations made of the relationship between the variable 'number of females in employment' and the outcome variable. It is not necessarily the case that the more females in employment will ultimately mean a better reception towards renewable energy sources, but merely that a higher number of females in employment is in part a result of a household with a larger number of occupants. These two variables ('number of females in employment' and 'total number of people in household') were found to have a significant association with each other so it is likely we are actually observing the overriding effect of the influencing factor the variable 'total number of people in the household'.

As the number of windows in the household increased, so did the likelihood that respondents would want renewable energy sources to be used over current means. This could be due to several factors but the most plausible reasoning would be that households with more windows are likely to be larger and thus have more people residing within it. This is supported by the additional variable analysis which showed a significant positive correlation between this variable and the variable 'total number of people in household'. Once again this highlights the total number of people in the household as being a significant overriding factor in influencing a respondent's belief in using renewable energy sources over current means of energy generation.

The factors above are all interlinked. The variable 'total number of people in household' was however the only variable to exhibit significant associations with all of the other variables that were found to be significantly associations with outcome variable ('do you think these types energy should be used over current means of energy provisions?’). This would suggest that this variable is therefore noteworthy and ‘useful’ when considering factors that could be used as indicators for how a respondent would feel about the use of renewable energy sources over their current means.

Outcome variable: Would you pay slightly more for energy from renewable or sustainable sources if you knew it was safer and more reliable?

The variable ‘would you pay slightly more for energy from renewable or sustainable source if you knew it was safer and more reliable?’ was found to be significantly associated with only one variable, ‘monthly electricity expenditure’. Respondents were more likely to pay slightly more for energy from renewable or sustainable source if it was safer and more reliable the higher their monthly expenditure on electricity was. A reason why these people were willing to pay slightly more for a renewable or sustainable energy source that is safer and more reliable may well be because they are happy with using these types of modern energy resources because of how easy they are to use but want something that is more reliable which would remove the need for using additional fuel sources (which all of the respondents did) which in turn could lead to an overall reduction in energy expenditure.

Reliability was highlighted during the descriptive analysis as a factor desired by respondents above safety so it is reasonable to surmise that is again the real factor here that is driving the respondent’s choice to say pay slightly more for a safer and more reliable supply.

The variable ‘total household fuel expense per month’ was found to be significantly associated with the variable ‘monthly electricity expenditure’. Respondents with a lower total monthly expenditure on electricity were more likely to have lower total household fuel expenditure per month as well as being more likely to pay slightly more for a safer and more reliable energy supply from renewable or sustainable sources. It is likely that although they have to make use of an alternative fuel for household lighting, which may suggest issues with the reliability of their main fuel, it is not that they do not desire the benefits that can be gained from the use of such energy sources but simply that they do not wish to pay more or in fact cannot afford to increase their monthly fuel expenditure beyond the level they are currently paying.

*Outcome variable: 'Would you pay part of the set up costs for a renewable or sustainable energy supply if it meant a safer supply'***.**

The variable 'Pay part of the set up costs for renewable or sustainable energy supply if meant a safer supply' was significantly associated with seven variables.

Respondents who indicated that they would be willing to contribute towards the set up costs of a renewable or sustainable energy supply if it meant a safer supply tended to have:

- A lower number of electrical lights in the household.
- Had access to electricity for a shorter period of time.
- A lower total household weekly income from employment.
- Lower male weekly incomes from employment.
- A lower monthly expenditure on transport.
- Use main fuel for lighting because: easily available.
- Not use paraffin/kerosene for household cooking.

Households with fewer electrical lights were more likely to pay towards the set up costs of a renewable or sustainable energy supply that offered a safer supply. These respondents were also more likely to have a lower monthly expenditure on transport and education fees. It could be surmised that these households had fewer outgoings per month and thus had the ability to reallocate funds to enable them to pay towards the set up costs. Whereas respondents from households which had a higher monthly expenditure had less flexibility to do so.

Another explanation could be that respondents whose households had a higher number of electrical lights were less likely to pay towards the set up costs of a renewable or sustainable energy supply that offered safer energy because they considered electricity to be a safe source of energy. Thus they did not see the need to pay towards an alternative supply that specifically offered this attribute. This could also be the reason why respondents from households that had access to electricity for a longer period of time were also less likely to contribute as they were content with the level of safety they experienced. As these two variables were not significantly correlated with each other, and there is no evidence that one is exerting any influence on the other, it is reasonable to assume that it is the confidence in their current energy supply that affects their attitude towards paying.

Respondents from households which had a higher weekly income from employment were less likely to pay towards the set up costs for a safer energy supply. This could be because safety is not a property desired enough on its own in an energy source that it would warrant additional expenditure. Households with a lower weekly income from employment were more likely to pay towards the set up costs for a safer energy supply. They were also less likely to buy all of the fuels they use and more likely to use firewood/biomass for household cooking. It is plausible that the firewood/biomass used is the source of fuel that these households do not have pay for. Firewood/biomass fuels have been previously shown to be a major cause of acute respiratory disease in India as discussed earlier (IEA 2007, Smith 2000).

Extended use of 'modern' cleaner fuels may be an unviable and unaffordable solution for households with lower incomes who are forced to make use of the cheaper fuels available regardless of the health hazards they present. It therefore makes sense that they would be willing to contribute towards the setup of an energy source that would ultimately give them access to a safer supply. It is the desire for a safer fuel that is the driving force behind a respondent's willingness to contribute towards set up costs. As it is only those households on lower incomes who are in need of such an energy supply, it is only from respondents from these households that we see this mind-set.

Households where the male weekly income was lower were more likely to pay towards the set up costs for a safer energy supply. This variable was found to be significantly associated with the variable 'total household weekly income from employment'. Unsurprisingly, as the male weekly income per household increases so does the total household weekly income. The reasons for why male weekly income is significantly associated with the outcome variable are probably as a result of its close association with the variable 'total household weekly income from employment' which arises from the fact that male weekly income represents the main source of household income. Thus the same factors highlighted and discussed previously relating to total household weekly income from employment explains why respondents would pay towards set up costs for a safer supply. Although as male weekly income was found to have a very strong association with the total household weekly income from employment, it could be used as an indicator to proxy for it and the same conclusions be drawn.

The reason why respondents from households with a higher monthly expenditure on transport were less likely to pay towards the set up costs of a renewable or sustainable energy supply even if it meant a safer supply may be because they do not consider safety an important enough factor to warrant the additional expenditure or because it is an unviable option because of an already stretched household budget.

Respondents who came from households with a lower monthly expenditure on transport were more likely to pay towards the set up costs because they did not have such constrained household budgets, thus could reallocate to cover the costs. The reasons for why they would want to do this are explained by the significant associations between ‘monthly expenditure on transport’ and ‘total number of electrical lights’ and ‘firewood/biomass used for household cooking’.

The respondents from households with lower monthly transport expenditure were also more likely to come from households that used firewood/biomass for household cooking and used fewer electric lights. The reasons for why these factors are important in influencing a respondent’s choice to pay towards set up costs have been discussed previously. It is plausible that these relationships are the real motivation for why these respondents would reallocate what money they had to fund such a project as they are considering the long term benefits a safer supply would offer, such as improved health. This highlights that having the flexibility to reallocate funds is as important a factor as having the funds available in the first place, and that exploring the different levels of household expenditure could be used as a means of determining whether the burden is substantial enough that it would limit the ability to reallocate funds and could help identify target areas in order to mitigate some of the financial constraints. Even with this the respondents are unlikely to invest if an energy source does not offer them enough of an incentive to do so, it must offer a property that is desired, which in this example was a safer supply.

All of the respondents used electricity as their main energy source for lighting. However, respondents who used this energy source because it was easily available were more likely to pay towards the set up costs of a renewable or sustainable energy source if it also meant a safer supply. These respondents were also from households which had access to electricity for a shorter period of time, used fewer electrical lights and had a smaller total weekly income from employment. The reasons why these respondents were more likely to pay towards set-up costs is possibly because they did not consider electricity a ‘safe’ energy source and are only making use of it because of its availability- the lack of confidence is further demonstrated by the fact that they use fewer electrical lights. This could just be a temporal factor which may diminish as confidence increases the longer the energy source is used, which would further explain why respondents who have had access to electricity for a longer period of time and use more electric lights are less likely pay towards the set up costs just for a safer supply.

A further explanation may be provided by exploring the significant correlation between ‘reasons for using fuel for lights: easily available’ and the variable ‘total household weekly income from employment’. Households with a smaller total weekly income may be unable to afford or access other energy sources that are available and therefore have no choice but to use what is available to them even if it is considered ‘unsafe’. Safety therefore would be a desirable characteristic to these respondents who would be willing to pay towards an energy resource that would provide them with access to such an energy supply.

The respondents from households that use paraffin/kerosene for household cooking were less likely to pay towards the set up costs of a renewable or sustainable energy supply even if it meant a safer supply. The most plausible explanation for this is that these respondents already consider paraffin/kerosene to be a safe energy source and therefore do not see the need in contributing towards the set up if this is the only benefit they will acquire. It is the same reasoning offered for why respondents who had access to electricity for a longer time and used more electrical lights were also less likely to pay towards the set up costs. Both of these two variables were significantly associated with ‘paraffin/kerosene used for cooking’ with the same group of respondents across them less likely to pay towards the set up.

An alternative reason could be that the respondents of households that did not use paraffin/kerosene for household cooking who were more likely to pay towards the set up costs for a safer supply were more aware of some of the hazards associated with using this fuel (poisoning, explosions, fire, low birth weight, increased risk of respiratory problems and cancer (Epstein *et al.* 2013, Lam *et al.* 2012, WHO 2009)). These respondents are also from households with lower weekly incomes from employment which as shown earlier are the households that were more likely to use firewood/biomass for cooking. As such it is possible that respondents desired a safer energy source to meet their energy needs but because paraffin/kerosene is not perceived to be safe, the respondents are willing to pay towards the set up in order to access a safer supply.

Out of the variables that were found to be significantly associated with the outcome variable, ‘total household weekly income from employment’ and ‘number of years household has had access to electricity’ appear to be the most useful indicators for whether people are more or less likely to pay towards the set up costs of a renewable or sustainable energy source if it meant a safer supply. However both of these variables appear to be influenced by secondary factors which may well provide the actual reasons for why respondents were more or less likely to pay towards the set up costs for a safer supply. Although these variables could still be used, used alone they may not provide a true reflection and lead to improper conclusions being drawn.

Outcome variable: ‘Would you pay part of the set up costs for a renewable or sustainable energy supply if it meant a more reliable supply’.

Five variables were found to be significantly associated with the outcome variable ‘Would you pay part of the set up costs for a renewable or sustainable energy supply if it meant a more reliable supply’**.** Respondents who indicated that they would be willing to contribute towards the set up costs of a renewable or sustainable energy supply if it meant a more reliable supply tended to come from household which:

- Did not use mud as main material for roofing.
- Had a higher number of permanent occupants.
- Had a higher number of windows in household.
- Have had access to electricity for a shorter length of time
- Has a smaller number of people in the household

Respondents from households that did not use mud as their main roofing material were more inclined to pay towards the set up costs for a more reliable supply. This could be because they were also the households with a higher number of permanent occupants. This in turn could mean that these households have a higher demand for energy and therefore would need a supply that is reliable in order to meet this demand. It could also be that the desire for a reliable energy supply derives from the activities for which it is used for; households with a higher number of permanent occupants were more likely to have or want to own a freezer. An appliance such as this requires a constant energy supply in order to be worthwhile, and so a reliable energy supply is vital. The households were also more likely to have a higher number of people in employment, which may make contributing towards the set up costs more realistic and feasible.

The variable ‘number of windows in the house’ was not only significantly associated with the outcome variable but also the variable ‘number of permanent occupants’. The more windows, the larger the number of permanent occupants. It is likely that it is this relationship that offers the real reason why the respondents were willing to pay towards the set up costs, because as already discussed a larger number of occupants requires a more reliable energy supply to meet a higher level of energy demand.

Respondents from households with a larger number of windows were also more likely to say that they used an alternative energy source for lighting when there were power cuts. This too could explain why they are willing to pay towards the setup of a more reliable supply because their current supply was not reliable enough.

Respondents from households which had access to electricity for a shorter length of time were more likely to pay towards the set up costs of a renewable or sustainable energy supply that was more reliable. This could be because they did not consider electricity to be a reliable fuel but did desire a source of modern energy. We know from the descriptive analysis of the survey results that electricity was used by all of the respondents for household lighting. The respondents from households which had access to electricity for a shorter period were more likely to say that the reason they used the main fuel they do for household lighting (electricity) was because it was ‘easily available’. This implies that they are only making use of electricity because of availability. If another source of modern energy (such as one from a renewable or sustainable source) became as easily available it is plausible that these respondents would switch to it, especially if the source was also more reliable.

It is interesting however to note that despite the respondents who had access to electricity for a longer period of time being more unhappy with the main fuel for lighting because it was unreliable, they were less likely to pay towards the set up costs even if it offered a more reliable energy source. The only explanation for this is that these households do not have the financial resources to be able to contribute. This might not be solely because of a lack available capital but also because of a lack of flexibility in how the household income can be spent.

4.3.3. Erroneous Variables

Some of the variables that were found to be significantly associated with the outcome variables from section 6 of the survey were excluded from the final analysis. The variables and the reasons they were omitted are given below.

Female weekly income was found to be significantly associated with the outcome variables ‘If the cost of using these sources was the same as your current supply would you consider switching over if: you knew it was helping protect the local environment?’ and ‘Would you pay part of the set up costs for a renewable or sustainable energy supply if it meant: a safer supply’. There were no obvious links between these sets of variables and upon further examination of the survey results it was found that the variable ‘female weekly income’ had a high proportion of ‘missing’ values which could be affecting its associations with other variables.

‘Steel used as main material for roofing’ was the only variable significantly associated with the outcome variable ‘Pay Slightly more for energy from renewable/sustainable sources if helping protect local environment’. Again there were no obvious links between the two, furthermore no additional variables were found to be significantly associated with the variable ‘steel used as main material for roofing’ making it impossible to infer as hidden relationship between it and the outcome variable.

The variable ‘kettle ownership’, which was significantly associated with the outcome variable ‘would you pay part of the set up costs for a renewable or sustainable energy supply if it meant: a more reliable supply?’ was omitted as no sensible link could be made to explain the relationship between the two.

The variable ‘total number of people in household’ which was significantly associated with the outcome variable ‘would you pay part of the set up costs for a renewable or sustainable energy supply if it meant: a more reliable supply?’ was also excluded from analysis. This was to avoid repetition as it was strongly associated with the variable ‘number of permanent occupants in household’. The two variables also shared similar significant associations with key variables highlighted through the additional analysis.

In many of the variables omitted, the size of the data sample could also be responsible as one of the dangers of using such a small sample is that it easier for false significant associations to occur especially when questions are not completed by all of the respondents. The use of a larger sample would help highlight and strengthen the evidence for significant associations and avoid such errors.

4.4. Respondent & Interviewer Feedback

One of the main aims of this study was to test the methodology of using an interview style questionnaire, as part of this each respondent and interviewer were asked to complete a short assessment form in order to help highlight any issues which were experienced and suggest ways of improving the survey or the guidelines and notes they were provided with the survey which could be used to enhanced the survey. This would ultimately lead to an increased response rate and increased accuracy of responses.

Interviewer Feedback

The interviewers reported that the questions on household heating were not perceived as important by respondents because of the fact that heating is rarely used and that for question 3.18 and some of the questions in section 5, in particular question 5.4, many respondents were more able to give these values in per year or per month. One interviewer noted that some respondents found the question that differentiated energy usage between seasons (winter/summer) difficult to understand as there was little difference in the seasons.

All of the interviewers indicated that they experienced no problems translating the survey and subsequent responses from or to English. The interviewers also indicated the survey guidelines and notes that they were provided with were useful and gave a clear outline of how to complete the survey form, in particular the examples given for some questions made it clearer which helped translate questions and answers to and from the local dialect. There were no questions highlighted by the interviewers that needed further explanation or clarification. Recommendations given as to how the guidance and notes could be improved included adding some local terminology and to include more photos or illustrations as these were highlighted particularly useful.

A further recommendation made by one of the interviewers was that an officially translated survey might be needed for a larger scale survey.

Respondents' Feedback

The average time to complete the survey was 45 minutes. All of the respondents indicated that they were happy with the way the questions were asked and the orders in which they were asked. Furthermore all of the respondents indicated that they found it easy to follow the interviewers.

The questions relating to household heating were highlighted by some respondents as questions that they thought were not relevant, because these respondents did not need to heat there households. One respondent felt some of the questions were being repeated. This may have been caused by the same questions being asked but in relation to fuels used for different household activities.

All of the respondents found the cover letter to be clear in explaining the surveys purpose and left them with no outstanding questions. Only two respondents indicated that they would have liked to have been provided with a copy of the cover letter to keep.

4.5. Alteration For Survey

The questions on household heating were left in the survey as although it was not perceived as important by these respondents, in a different village or region of the country it may have been a more important factor for energy demand. For similar reasoning the questions which used seasons to explore changes in energy usage were left in as most regions do experience seasonal changes.

The addition to the time scale option ‘per month’ was added in to question 3.18 and question 3.26 and ‘per year’ was added to question 5.4 as per the recommendations made by the interviewers.

At the beginning of the section on energy for household heating and cooling in section 3 of the survey, question 3.20 was changed to include a yes or no option for whether respondents typical needed to heat the household in winter and/or summer. If the respondents answered no to both parts they would be directed to skip to question 3.28. They would only need to complete the subsequent question if they answered yes to one or both parts of question 3.20.

To reflect the changes made to the questionnaire the survey guidelines and notes for the interviewers were updated and in places rewritten to make the instructions more concise.

4.6. Summary

This study found using interview surveys to be an appropriate means for exploring rural energy usage and the attitudes of rural communities towards modern energy supplies.

Primary data was collected for household energy use and a summary of the typical Uddhar household given. Lighting, cooking and cooling of the household form the main areas of household energy demand. The factors that affected the selection of energy resources were highlighted with availability being identified as potential important underlying aspect. A relationship between the cost of a fuel and how easy it is to use was also identified suggesting that ease of use was sacrificed in favour of a cheaper energy source. Cost appears to be the primary limiting factor in fuel selection with people desiring an easy to use fuel but being unable to afford those that are available.

The opportunities for and barriers against the use of renewable and sustainable energy resources have been identified. There is interest in using sustainable or renewable energy sources over more traditional means of energy generation. Several factors could be used as indicators for assessing a respondent's attitude towards the use of renewable or sustainable energy resources. In addition, these indicators could be used to target individuals in order to improve acceptance of renewable and sustainable energy resources. Despite these indicators, the use of renewable/sustainable energy sources alone is not enough of a reason for respondents to switch to or contribute towards their setup they must offer more than just being a renewable source and must come in the form of an affordable, reliable and easy to use energy resource.

As this study focused on only one village it is unlikely to be representative of the state or country at large. Therefore a study exploring the energy requirements and attitudes towards alternative modern energy provision of a larger rural population is needed. This could help confirm the initial findings, support the use of this methodology and further highlight common attitudes and barriers as well as differences that might be overlooked when not considering villages as separate self-contained systems.

Chapter 5. Exploring Potential Opportunities & Barriers To The Uptake Of Renewable Energy Technologies In The Indian State Of Orissa

5.1. Introduction

As highlighted in previous chapters, information on energy access in rural and remote areas of developing countries is not always readily available. Furthermore the attitudes of stakeholder communities are often overlooked when it comes to the implementation of modern energy projects (Moomow *et al.* 2011, Painuly 2001). Acceptance is a key requirement for the implementation of any RET project. Without it, market viability can be undermined and their long term success reduced (Moomow *et al.* 2011, Painuly 2001).

This chapter aims to explore the current energy usage and needs of India's rural communities, highlight the requirements for modern energy access and identify the opportunities for, and barriers to, the expanded use of renewable energy sources.

5.2. Methods & Approach

This work builds on the methodology and results from the design and implementation of the rural energy survey presented in Chapter 4 by obtaining data using a refined version of the survey (Appendix 7) which incorporates alterations recommended in Chapter 4.5 to the design and methods of the survey and a larger rural sample.

The methods and approaches undertaken in the completion of the rural energy survey described in this chapter, and how the data was collected and subsequently analysed can be found in Chapter 3.1.

5.3. Results

5.3.1. Respondent's Demographics

The survey consisted of ninety seven respondents, 12.4% were from the Cuttack district and 87.6%, from Khordha. All the respondents from Cuttack came from one village and those from Khordha were drawn from twelve separate villages. The number of respondents from each village is shown in the Table 5.1 below.

Table 5.1: Number of responses per village

Village	Frequency	Percent
Balipada	2	2.1
Barang	2	2.1
Bhumipua	1	1.0
Bhunlis	1	1.0
Dadhapatna	12	12.4
Dihapura	11	11.3
Jahala	22	22.7
Kendubarane	2	2.1
Kendupatna	1	1.0
Panola	1	1.0
Shishupal Garh	12	12.4
Baronga	2	2.1
Tamando	28	28.9
Total	97	100.0

The age of respondents ranged from under sixteen to over sixty-one, although the most common age groups were 21-25 *(15.5%, n=15)*, 41-45 *(13.4%, n=13)* and 61+ *(12.4%, n=12)*. A full breakdown of the respondent age groups is shown in Table 5.2. Male participants accounted for 69.5% *(n=66)* of respondents, female the remaining 30.5% *(n=29)*.

Table 5.2: Number of respondents by age group

Age band	Frequency	Percent
Under 16	1	1.0
16 - 20	6	6.2
21 - 25	15	15.5
26 - 30	12	12.4
31 - 35	11	11.3
36 - 40	9	9.3
41 - 45	13	13.4
46 - 50	8	8.2
51 - 55	5	5.2
56 - 60	5	5.2
61+	12	12.4
Total	97	100.0

5.3.2. Household Information

This information was gathered in order to build a more complete picture of India's rural households, and is later used to see if any aspects could be used as indicators in identifying barriers to the use RETs.

The average number of permanent occupants living in a household was 5.8 individuals. The most common household sizes were 4 *(23.7%, n=23)* or 5 *(22.7%, n=22)* occupants (range 3-30).

Of the households surveyed, 84.0% *(n=79)* indicated that the head of a household was male and 16.0% *(n=15)* female. However, only 44.3% *(n=43)* indicated that the head of the household was responsible for deciding household fuel use.

Where the head of the household was not in charge of household fuels use *(n=54)*, the responsibility was shared in 40.7% *(n=22)* of cases. In 59.3% *(n=32)* of cases the responsibility fell to a female member of the household, in all of these instances the responsibility had been delegated from a male head of the household, which could possible indicate that fuel selection is very much seen as a female responsibility.

Overall 43.2% *(n=41)* of total respondents indicated that a female member of the household was responsible for deciding on household fuel use. In 33.7% *(n=32)* of responses a male member of the household was in charge, and in 23.2% *(n=22)* of cases the responsibility was shared between two or more members of the household.

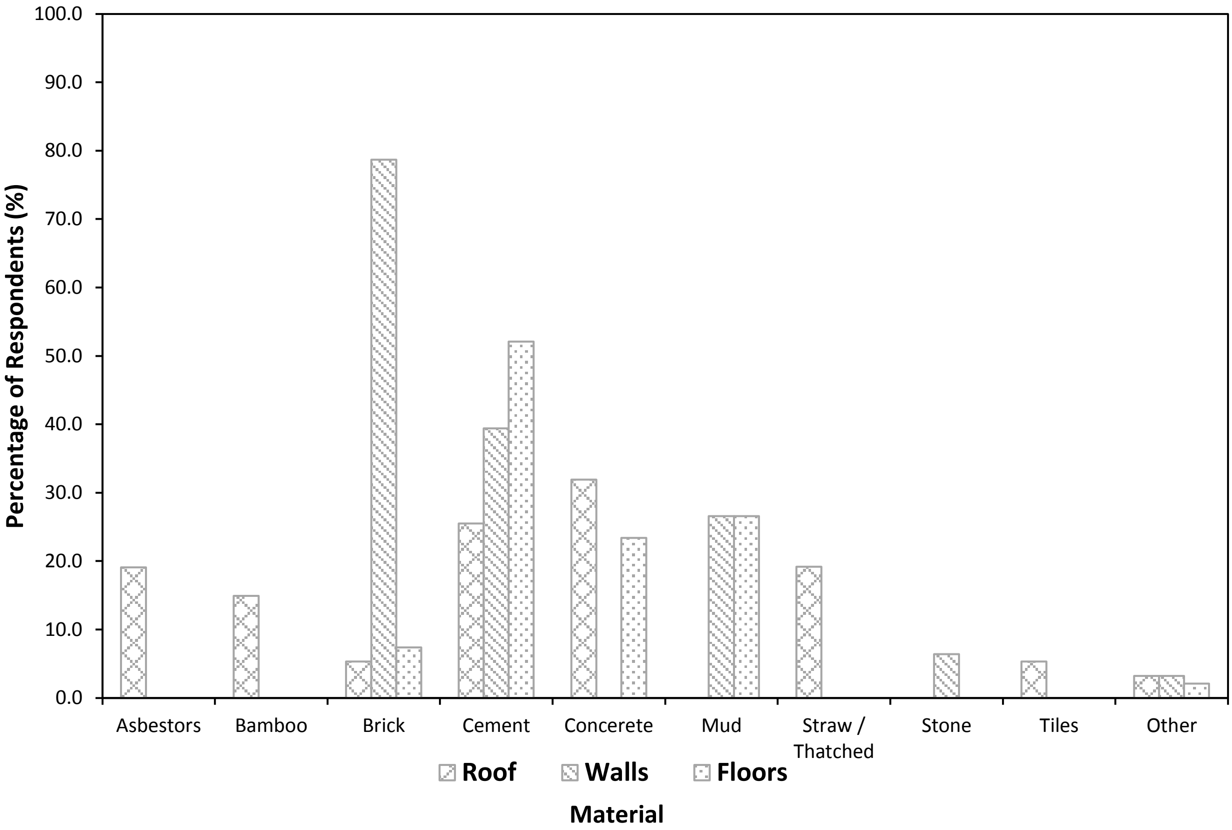
The vast majority *(80.0%, n=76)* of households surveyed were single story buildings. There were, however, cases of two and three story building also documented 15.8% *(n=15)* and 4.2% *(n=4)* respectively.

The majority of households had two entrances *(51.5%, n=50)*, the average being 1.65. These entrances were covered predominantly by wood *(78.5%, n=73)*, followed by tin *(11.3%, n=11)* or iron *(8.2%, n=8)*. Households had on average 3.3 windows that were permanently left open by 85.9% *(n=79)* of respondents.

The mean number of rooms per household was 3.8 rooms with the most common household sizes being those which consisted of 4 *(22.7%, n=22)* rooms followed by households comprised of 2 *(18.6%, n=18)* or 3 *(18.6%, n=18)* rooms, (range 1-20).

Figure 5.1 shows the materials used in household construction. Concrete *(31.2%, n=30)* and cement *(25.5%, n=24)* were the main materials used for roofing. Brick are by far the most popular material used in household walls with 78.7% *(n=74)* of respondents using it. Cement and mud were also highlighted as commonly used materials in walls construction used by 39.4% *(n=37)* and 26.6% *(n=25)* or respondents respectively. The main household flooring materials highlighted by respondents were cement *(52.1%, n=49)*, mud *(26.6%, n=25)* and concrete *(23.4%, n=22)*.

Figure 5.1: The application of materials in the construction of roofs, walls & floors.



Overall cement was the most popular material used throughout household construction with 70.2% *(n=68)* of respondents indicating its use in one or more areas of the household. Although brick is used by almost 80.0% of respondents, its application appears limited, being almost solely used for the construction of household walls.

When asked to give details about livestock kept and types of crops grown, 52.6% *(n=51)* of respondents kept livestock and only 27.8% *(n=27)* grew their own crops.

Of the respondents who kept livestock, cattle were the most common *(98.0%, n=50)*. Other livestock kept included goats *(9.8%, n=5)* and sheep *(3.9%, n=2)* but by far fewer respondents. Other unspecified livestock was kept by 7.8% *(n=4)* of respondents. On average a single animal was kept per household (range 1-16), and it likely that the animals kept were cattle.

Rice was grown by 92.3% *(n=24)* of respondents who indicated growing their own crops. A further 11.5% *(n=3)* of respondent grew a mixture of other unspecified crops. On average each household had access to 0.3 acres of land for crops; however the majority of household *(72.2%, n=70)* did not grow their own crops. When only including households that grew their own crops, the mean number of acres available per household was 1.4 acres. The smallest area used by a single household for growing crops was 0.25 acres, the largest was 11.0 acres.

5.3.3. Household Energy Usage

Energy For Lighting

The vast majority of respondents *(87.6%, n=85)* used electricity as their main energy source for lighting followed by 10.3% *(n=10)* using paraffin/kerosene and 2.1% *(n=2)* using firewood/biomass.

The reasons given by respondents for why they decided to use the primary fuel they used for household lighting are shown in Table 5.3. The main reasons given by respondents for selecting the fuels they used over others were because it was ‘easy to use’ *(92.8%, n=90)*, ‘easily available’ *(74.2%, n=72)*, a ‘familiar fuel’ *(50.5%, n=49)* and ‘cheap’ *(42.3%, n=41)*.

There are also differences observed in the reasons given for individual fuels. For example, ‘cannot afford other fuels’ and ‘cheap’ are reasons given by majority of respondents who use firewood/biomass or paraffin/kerosene. Whereas very few respondents gave them as reasons for why they used electricity.

Table 5.3: Reasons for selecting main fuel used for rural household lighting

		Main Energy Resource Used For household Lighting						
		Electricity (%) *(n=85)*	Total respondents (%) *(n=97)*	Firewood/biomass (%) *(n=2)*	Total respondents (%) *(n=97)*	Paraffin/kerosene (%) *(n=10)*	Total respondents (%) *(n=97)*	Total (%) *(n=97)*
Reasons For Selected Fuel Used	Cannot afford other fuels	1.2	1.0	100.0	2.1	70.0	7.2	10.3
	Cheap	37.6	33.0	100.0	2.1	70.0	7.2	42.3
	Easily available	75.3	66.0	100.0	2.1	60.0	6.2	74.2
	Easy to use	95.3	83.5	100.0	2.1	70.0	7.2	92.8
	Familiar Fuel	50.6	44.3	100.0	2.1	40.0	4.1	50.5
	Only fuel available	0.0	0.0	50.0	1.0	10.0	1.0	2.1
	Other	1.2	1.0	0.0	0.0	0.0	0.0	1.0
	Total	100.0	87.6	100.0	2.1	100.0	10.3	-

Table 5.4: Reasons unhappy with main fuels used for rural household lighting

		Main Energy Resource Used for Household Lighting						
		Electricity (%) *(n=23)*	Total respondents (%) *(n=31)*	Firewood/biomass (%) *(n=1)*	Total respondents (%) *(n=31)*	Paraffin/kerosene (%) *(n=7)*	Total respondents (%) *(n=31)*	Total (%) *(n=31)*
Reasons Unhappy With Selected Fuel	Expensive	47.8	35.5	0.0	0.0	14.3	3.2	38.7
	Health Concerns	0.0	0.0	100.0	3.2	28.6	6.5	9.7
	Smoky	0.0	0.0	100.0	3.2	14.3	3.2	6.5
	Takes too long to burn	0.0	0.0	100.0	3.2	0.0	0.0	3.2
	Unreliable	34.8	25.8	0.0	0.0	28.6	6.5	32.3
	Unsafe	0.0	0.0	100.0	3.2	28.6	6.5	9.7
	Other	21.7	16.1	0.0	0.0	57.1	12.9	29.0
	Total	100.0	74.2	100.0	3.2	100.0	22.6	-

When asked if they were happy with their primary energy resource used for household lighting 67.7% *(n=65)* of respondents were happy, and the remaining 32.3 percent *(n=31)* were not.

By individual energy resource, 72.6% *(n=61)* of respondents who used electricity, 50.0% *(n=2)* who used firewood/biomass and 30.0% *(n=3)* of paraffin/kerosene users indicated that they were happy with this fuel.

Table 5.4 shows the reasons given by respondents as to why they were unhappy with their primary fuel used for household lighting. The main reasons given by respondents who used electricity as their primary energy resource were because it was 'expensive' *(47.8%, n=11)* and 'unreliable' *(34.8%, n=8).*

'Health concerns', 'smoky', 'takes too long to burn' and 'unsafe' were reasons given by all respondents who used firewood/biomass. Respondents who used paraffin/kerosene as their primary fuel gave 'health concerns' *(28.6%, n=2)*, 'unreliable' *(28.6%, n=2)* and 'unsafe' as the main reasons for being unhappy with using this fuel.

Across all the fuels, the main reasons highlighted by respondents for being dissatisfied with their primary energy resource used for household lighting were because the fuel was 'expensive' *(38.7%, n=12)* and 'unreliable' *(32.3%, n=10).*

Only six respondents *(6.2%)* did not make use of an alternative energy supply for household lighting. The remaining 93.8% *(n=91)* indicated that in addition to their primary fuel they also made use of an alternative energy resource. 95.4% of respondents who were happy with their primary fuel resource still made use of an alternative energy resource.

Table 5.5 shows the alternative energy resources utilised by respondents in addition to their primary fuel. Paraffin/kerosene *(76.3%)* was the most popular alternative, followed by candles *(38.1%).*

91.5% of respondents *(n=75)* used alternatives over their primary energy resources during power cuts. A further 9.8% *(n=8)* said during the rainy season, and 7.3% *(n=6)* gave other reasons, which included when primary fuel ran out and to enable study. Table 5.6 shows the relationship between a respondent's primary energy resource and the reasons given to use an alternative over it.

Table 5.5: Primary & alternative energy resources used for rural household lighting

		Main Energy Resource Used For Household Lighting						
		Electricity (%) *(n=85)*	Total respondents (%) *(n=97)*	Firewood/biomass (%) *(n=2)*	Total respondents (%) *(n=97)*	Paraffin/kerosene (%) *(n=10)*	Total respondents (%) *(n=97)*	Total (%) *(n=97)*
Alternative Fuels used For Household Lighting	Candles	41.2	36.1	0.0	0.0	20.0	2.1	38.1
	Electricity	*n/a*	*n/a*	0.0	0.0	20.0	2.1	2.1
	Firewood/biomass	1.2	1.0	*n/a*	*n/a*	20.0	2.1	3.1
	LP Gas	3.5	3.1	0.0	0.0	0.0	0.0	3.1
	Paraffin/Kerosene	85.9	75.3	50.0	1.0	*n/a*	*n/a*	76.3
	Other	10.6	9.3	0.0	0.0	10.0	1.0	10.
	No Other Source Used	1.2	1.0	50.0	1.0	40.0	4.1	6.2
	Total	100.0	87.6	100.0	2.1	100.0	10.3	-

Table 5.6: Reasons for using alternative energy resource over primary for rural household lighting

		Main Energy Resource Used for Household Lighting						
		Electricity (%) *(n=75)*	Total respondents (%) *(n=82)*	Firewood/biomass (%) *(n=1)*	Total respondents (%) *(n=82)*	Paraffin/kerosene (%) *(n=6)*	Total respondents (%) *(n=82)*	Total (%) *(n=82)*
When is Alternative Energy Resource Used	During Power Cuts	100.0	91.5	0.0	0.0	0.0	0.0	91.5
	Rainy Season	9.3	8.5	100.0	1.2	0.0	0.0	9.8
	Other	0.0	0.0	0.0	0.0	100.0	7.3	7.3
	Total	100.0	91.5	100.0	1.2	100.0	7.3	-

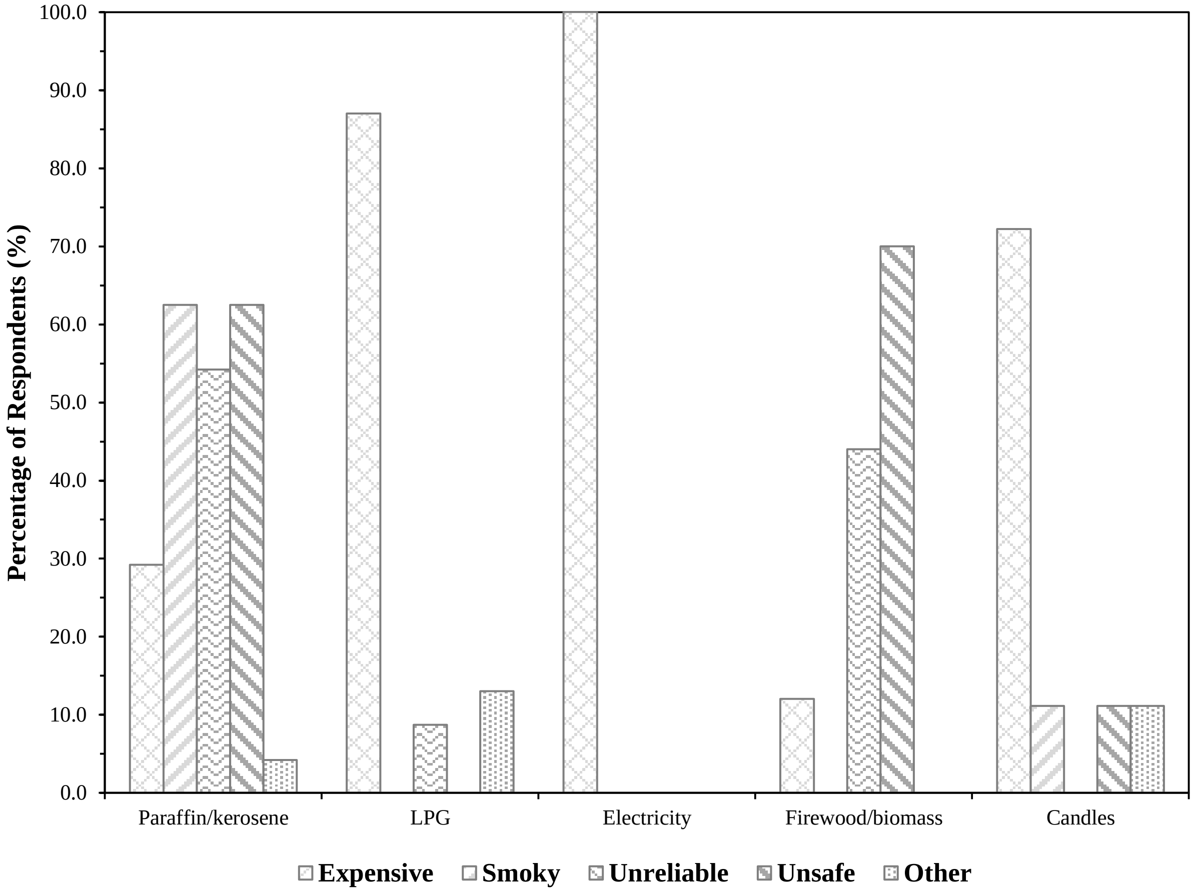
88.2% of respondents *(n=75)* who used electricity as their primary energy resource for household lighting cited power cuts as their reason for also using an alternative energy resource. This includes 85.2% *(n=52)* of the respondents who said they were happy with this energy resource. 34.8% *(n=8)* of the respondents who said they were unhappy using electricity cited 'unreliable' as one of the reasons why.

In addition to the fuels they had access to and used, respondents were also asked to give details of the other energy resources that were available to them and the reasons why they were not used. Only 20.6% *(n=20)* of respondents indicated that there were no other energy resources available that could have been used household lighting.

Of the respondents who did have access to an alternative energy resource for household lighting, 64.9% *(n=50)* of respondents had access to firewood or biomass, 59.7% *(n=46)* to LPG, 31.2% *(n=24)* to paraffin/kerosene, 23.4% *(n=18)* to candles and a further 10.4% *(n=8)* to electricity.

Figure 5.2 shows the reasons given by respondents for not using a specific fuel that was available to them for household lighting.

Figure 5.2: Reasons given by respondents for not using specific fuels for rural household lighting



Reasons given by respondents who had access to paraffin/kerosene but did not use it were ‘smoky’ *(62.5%, n=15)*, ‘unsafe’ *(62.5%, n=15)*, ‘unreliable’ *(54.3%, n=13)*, and expensive *(29.2%, n=7)*.

In addition, ‘Unsafe’, ‘smoky’, ‘unreliable’ and ‘expensive’ were all reasons highlighted by respondents who did use paraffin/kerosene as reasons why they were unhappy using this fuel for household lighting (Table 5.4).

Respondents chose not use LPG for household lighting despite it availability because it was ‘expensive’ *(87.0%, n=40)*, ‘unreliable’ *(8.7%, n=4)* and ‘other *(13.0%, n=6)*.

All of the respondents who did not use electricity despite it availability did so because of the high expense associated with its use. The expense of using this resource was also highlighted by 47.8% *(n=8)* of respondents as their reason for being unhappy with using this fuel their primary energy resource for household lighting. (Table 5.4).

98.0% *(n=49)* of respondents chose not to use firewood/biomass because it was ‘too smoky’. A further 70.0% *(n=35)* perceived it to be ‘unsafe’, 44.0% *(n=22)* ‘unreliable’ and 12.0% *(n=6)* because it was ‘expensive’.

Reasons given by respondents who had access to candles but did not use them were ‘expensive’ *(72.2%, n=13),* ‘unreliable *(22.2%, n=4),* ‘smoky’ *(11.1%, n=2)* and ‘unsafe’ *(11.1%, n=2)*.

Non-natural lighting was used by 8.2% *(n=8)* of respondents in the morning during winter and 6.2% *(n=6)* during the summer. On average those who did use non-natural light did so for 2.4 hours per day in the winter and 3.7 hours per day in the summer. More respondents made use of non-natural light in the evening in both summer and winter than the mornings. During winter and summer, 96.9% *(n=94)* of respondents lit their houses at night with non-natural lighting for an average of 5 hours per day in the winter and an average of 5.1 hours in the summer.

Only 15.5% *(n=15)* of households used artificial lighting to enable additional work to be carried out at night that would contribute to the household income. On average each household had 1.3 people working an additional 3.5 hours per day per household. This enabled an additional 24.3 hours of productive work per week in households that used artificial lighting for work.

Respondents also gave details of the different light sources they used. 89.7% *(n=87)* of respondents used electrical lights. 89.7% *(n=87)* used fuel lamps or lanterns. 2.7% *(n=2)* used open fires and 6.2% *(n=6)* used other non-descript sources.

The average number of electric lights used per household was 5.2, (range 1-20). On average there were 1.7 fuel lamps/lanterns per household (range 1-8) consuming an average of 0.1 litres of fuel per day (range 0.01-6.0). The average number of open fireplaces per household was 2.5 (range 2-3). The average fuel consumption was 3.3 kg per day (range 2.0-5.5).

The respondents who used electric lights for household lighting were asked to identify the different lights they used and if possible their wattage (per hour). The most popular types of lights used for rural household lighting were energy saving lights *(80.5%, n=70)* and filament (incandescent) lights *(56.3%, n=49)*. Only 14.9% *(n=13)* of respondents use fluorescent lights and only 1 respondent *(1.1%)* used LED lights.

Table 5.7 provides a breakdown of the different lights used and a count of the different lights according to their wattage. Energy saving lights were used most frequently *(n=338)*, with the 20 watt energy saving bulb being the most numerous single light source used *(n=114)*, closely followed by the 100 watt filament bulb *(n=112)*. The 100 watt filament bulbs were used by 87.8% *(n=43)* of respondents who used filament lights. The 20 watt energy saving light bulbs, however, were only used by 42.0% *(n=29)* of the respondents who used energy saving lights.

Table 5.7: Count of electric lights used in rural households for lighting

		Types of Lights Used								
		Energy saving		Filament (incandescent)		Fluorescent		LED		
		Number of lights	Total respondents (%) *(n=69)*	Number of lights	Total respondents (%) *(n=49)*	Number of lights	Total respondents (%) *(n=13)*	Number of lights	Total respondents (%) *(n=1)*	Total lights per wattage
Wattage of lights used	100	3	2.9	112	87.8	0	n/a	0	n/a	115
	60	46	21.7	3	4.1	4	7.7	2	100.0	55
	40	30	17.4	0	n/a	21	69.2	0	n/a	51
	35	25	10.1	0	n/a	0	n/a	0	n/a	25
	25	9	4.3	2	n/a	0	n/a	0	n/a	11
	20	114	42.0	12	4.1	2	7.7	0	n/a	128
	18	49	13.0	5	2.0	0	n/a	0	n/a	54
	15	30	8.7	0	n/a	0	n/a	0	n/a	30
	14	11	2.9	0	n/a	3	7.7	0	n/a	14
	Other	21	4.3	6	8.2	1	7.7	0	n/a	28
	Total	338	100.0	140	100.0	31	100.0	2	100.0	511

The average household used energy saving light bulbs solely *(41.4%, n=36)* however 27.6% *(n=24)* of respondents used a combination of both energy saving and filament bulbs. Filament and energy saving lights in conjunction or separately accounted for 83.9% *(n=73)* of the lights used by respondents, with the ratio of filament light bulbs to energy saving being 1:2.4.

Energy For Cooking

The number of hours spent cooking per day ranged from 1.0-7.0 hours, with the average being 2.5 hours a day. The most common lengths of time spent cooking were 2.0 hours *(26.8%, n=26)* and 1.5 hours *(24.7%, n=24)* per 24 hours.

The primary energy sources used by respondents for household cooking were firewood/biomass *(64.9%, n=63)*, LPG *(30.9%, n=30)*, paraffin/kerosene *(3.1%, n=3)* and electricity *(1.0%, n=1)*.

The reasons given by respondents for why they decided to use the primary fuel they did for household cooking are shown in Table 5.8. The main reasons respondents gave for using the primary fuel resource they did over others available were because it was 'easy to use' *(82.3%, n=79)*, 'easily available' *(76.0%, n=73)*, cheap *(68.8%, n=66)* and a familiar fuel *(59.4%, n=57)*.

In addition 30.2% *(n=29)* of respondents used their primary fuel because they could not afford any other fuel available. Only 5.2% *(n=5)* of respondents indicated that there were no other fuels available, and 2.1% *(n=2)* of respondents gave other nondescript reasons.

38.1% *(n=37)* of respondents were unhappy with the primary energy resource they used for household cooking. Of these respondent, 91.9% *(n=34)* used firewood or biomass as their primary energy resource, and represented 54.0% of all firewood or biomass users *(n=63)*. 5.4 percent *(n=2)* of those who were unhappy used LPG as their primary energy resource and accounted for only 6.7% of all LPG users *(n=30)*. The final 2.7% consisted of a single respondent using paraffin/kerosene as their primary fuel.

Table 5.8: Reasons for selecting main fuel used for rural household cooking

		Main Energy Resource Used For household Cooking								
		Electricity (%) *(n=1)*	Total respondents (%) *(n=96)*	Firewood/ biomass (%) *(n=63)*	Total respondents (%) *(n=96)*	LP Gas (%) *(n=30)*	Total respondents (%) *(n=96)*	Paraffin/ kerosene (%) *(n=2)*	Total respondents (%) *(n=96)*	Total (%) *(n=96)*
Reasons For Selected Fuel Used	Cannot afford other fuels	0.0	0.0	46.0	30.2	0.0	0.0	0.0	0.0	30.2
	Cheap	100.0	1.0	88.9	58.3	26.7	8.3	50.0	1.0	68.8
	Easily available	0.0	0.0	74.6	49.0	80.0	25.0	100.0	2.1	76.0
	Easy to use	100.0	1.0	74.6	49.0	96.7	30.2	100.0	2.1	82.3
	Familiar fuel	100.0	1.0	61.9	40.6	53.3	16.7	50.0	1.0	59.4
	Only fuel available	0.0	0.0	6.3	4.2	3.3	1.0	0.0	0.0	5.2
	Other	0.0	0.0	0.0	0.0	6.7	2.1	0.0	0.0	2.1
	Total	100.0	1.0	100.0	65.6	100.0	31.3	100.0	2.1	-

Table 5.9: Reasons unhappy with main fuels used for rural household cooking

		Main Energy Resource Used for Household Cooking				
		Firewood/biomass (%) *(n=34)*	Total respondents (%) *(n=36)*	LPG (%) *(n=2)*	Total respondents (%) *(n=36)*	Total (%) *(n=36)*
Reasons Unhappy With Selected Fuel	Expensive	14.7	13.9	50.0	2.8	16.7
	Health Concerns	73.5	69.4	0.0	0.0	69.4
	Smoky	97.1	91.7	0.0	0.0	91.7
	Takes too long to burn	14.7	13.9	0.0	0.0	13.9
	Unreliable	52.9	50.0	50.0	2.8	52.8
	Unsafe	64.7	61.1	0.0	0.0	61.1
	Other	2.9	2.8	0.0	0.0	2.8
	Total	100.0	94.4	100.0	5.6	-

Table 5.9 shows the reasons given by respondents as to why they were unhappy with their primary fuel used for household cooking. Nearly all of the respondents who used firewood or biomass for household cooking gave ‘smoky’ *(97.1%, n=33)* as one of the main reasons for being dissatisfied with using this fuel. ‘Health concerns’ were cited by 73.5% *(n=25)* of respondents as well as ‘unsafe’ *(64.7%, n=22)* and ‘unreliable’ *(52.9%, n=18)*, 14.7% *(n=5)* of respondents were dissatisfied with using firewood or biomass for household cooking because it takes ‘too long to burn’.

The two respondents who said they were unhappy using LPG for household cooking gave ‘unreliable’ *(50.0%, n=1)* and ‘expensive’ *(50.0%, n=1)* as reasons for being dissatisfied with this fuel. No reason was given by the single respondent who was unhappy using paraffin/kerosene as their primary energy resource for household cooking.

Across all the fuels, the main reasons highlighted by respondents for being dissatisfied with their primary energy resource used for household cooking were because the fuel was ‘smoky’ *(91.7%, n= 33)*, provided ‘health concerns’ *(69.4%, n=25)* and because the fuel was considered ‘unsafe’ *(61.1%, n=22)*.

As well as their primary fuel used for household cooking, 72.2% *(n=70)* of respondents also made use of an alternative energy resource for household cooking. 70.0% *(n=42)* of respondents were satisfied with their primary energy resource used for household cooking also made use of an alternative. Of the respondents who were not happy with their primary energy resource, 75.7% *(n=9)* made use of at least one alternative resource. Only 24.4% *(n=9)* of respondents indicated that despite being unhappy made no use of an alternative.

Table 5.10 shows the primary and alternative energy resources utilised by respondents. Paraffin/kerosene *(48.5%, n=47)* was the most popular alternative resource followed by firewood/biomass *(30.9%, n=30)*, LPG *(13.4%, n=13)* and electricity *(3.1%, n=3)*.

Nine *(14.3%)* respondents who used firewood/biomass as their primary energy resource for household cooking also used firewood/biomass as an alternative. In these cases, the respondents were switching between two different forms of this energy resource, e.g. cow dung from firewood.

Table 5.10: Primary & alternative energy resources used for rural household cooking

		Main Energy Resource Used for Household Cooking								
		Electricity (%) *(n=1)*	Total respondents (%) *(n=97)*	Firewood/ biomass (%) *(n=63)*	Total respondents (%) *(n=97)*	LPG (%) *(n=30)*	Total respondents (%) *(n=97)*	Paraffin/ kerosene (%) *(n=3)*	Total respondents (%) *(n=97)*	Total (%) *(n=97)*
Alternative Fuels Used For Household Cooking	Electricity	*n/a*	*n/a*	0.0	0.0	10.0	3.1	0.0	0.0	3.1
	Firewood/biomass	100.0	1.0	14.3	9.3	60.0	18.6	66.7	2.1	30.9
	LP Gas	0.0	0.0	17.5	11.3	*n/a*	*n/a*	66.7	2.1	13.4
	Paraffin/kerosene	100.0	1.0	44.4	28.9	60.0	18.6	*n/a*	*n/a*	48.5
	No other source used	0.0	0.0	38.1	24.7	10.0	3.1	0.0	0.0	27.8
	Total	100.0	1.0	100.0	64.9	100.0	30.9	100.0	3.1	100.0

Table 5.11: Reasons for using alternative energy resource over primary for rural household cooking

		Main Energy Resource Used for Household Cooking								
		Electricity (%) *(n=1)*	Total respondents (%) *(n=63)*	Firewood/ biomass (%) *(n=36)*	Total respondents (%) *(n=63)*	LPG (%) *(n=23)*	Total respondents (%) *(n=63)*	Paraffin/ kerosene (%) *(n=3)*	Total respondents (%) *(n=63)*	Total (%) *(n=63)*
When is Alternative Energy Resource Used	When Raining	0.0	0.0	44.4	25.4	4.3	1.6	0.0	0.0	27.0
	Primary Fuel unavailable	0.0	0.0	27.8	15.9	82.6	30.2	33.3	1.6	47.6
	Depends On Fuels Available	0.0	0.0	19.4	11.1	4.3	1.6	0.0	0.0	12.7
	Other	100.0	1.6	16.7	9.5	13.0	4.8	66.7	3.2	19.0
	Total	100.0	1.6	100.0	57.1	100.0	36.5	100.0	4.8	100.0

When asked when they use these alternatives over their primary energy resource, 47.6% *(n=30)* of respondents did so when their primary fuel was unavailable, 27.0% *(n=17)* when it was raining, 12.7% *(n=8)* used alternatives depending upon the fuels that were available at the time and 19.0% *(n=12)* gave other nondescript reasons. Table 5.11 shows a respondent's primary energy resource and the reasons given to use an alternative over it.

Respondents were asked to give an indication of how much of each fuel they consumed for household cooking they use over a monthly period.

The mean household consumption of paraffin/kerosene was 3.2 litres per month and ranged from 0.5 litres to 15.0 litres a month. Respondents who utilised LPG for household cooking on average consumed 15.3 litres per month, with consumption ranging from 3.5 litres to 52.3 litres a month, and the most frequent level of consumption being 14.2 litres a month *(25.6%, n=10)*, followed by 25.7 litres a month *(23.1%, n=9)*. The average volume of firewood or biomass consumed for household cooking was 124.7 kg per month (range 5.0-900 kg per month).

Paraffin/kerosene is used by more respondents as an alternative energy source for household cooking than a primary source. LPG and firewood/biomass are however used principally as a primary energy source with more respondents using them for this purpose than as an alternative energy source (see Table 5.10). In addition the average consumption of each of these fuels varied between those who used it as their primary fuel and those who used it as an additional energy resource for household cooking.

The respondents who use paraffin/kerosene as their primary resource *(3.1%, n=3)* had an average consumption of 10.3 litres per month, compared to respondent who only used it as an alternative *(48.5%, n=47)* where average of 2.8 litres per month was consumed. A similar pattern is seen in the consumption of firewood/biomass for household cooking. Those who used it as their primary energy resource *(64.9%, n=63)*, had an average monthly consumption of 168.4 kg, compared to those who used it as an alternative *(30.9%, n=30)* where 62.0 kg per month was consumed.

Those who used LPG as their primary energy resource *(30.9%, n=30)* consumed an average of 17.2 litres per month, respondents who used it as an alternative *(13.4%, n=13)* consumed only 11.3 litres per month (Table 5.12).

There is a disparity in the volumes of fuel consumed by respondents depending on whether the fuel is used by as a primary or alternative supply for household cooking.

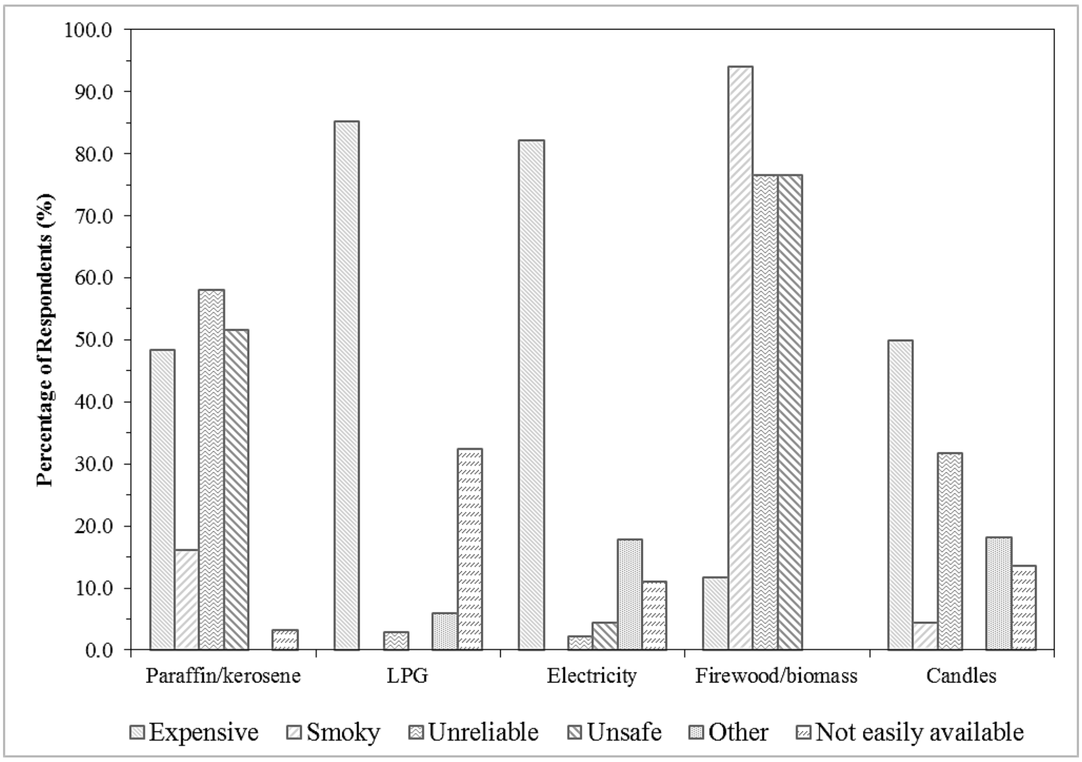
Table 5.12: Variation in average consumption of primary & alternative fuels used for rural household cooking

		Energy Resource Used for Household Cooking		
		Firewood/biomass (kg/month)	Paraffin/kerosene (L/month)	LP Gas (L/month)
Level of Fuel usage	Primary	168.4	10.3	17.2
	Alternative	62.0	2.8	11.3

Seventy-nine *(81.4%)* respondents indicated that other fuels were available but were not used for household cooking. Of these respondents 57.0% *(n=45)* had access to electricity, 43.0% *(n=34)* to LPG, 39.2% *(n=31)* to paraffin/kerosene, 27.8% *(n=22)* to candles and 21.5% *(n=17)* to firewood or biomass. In addition, 2.5% *(n=2)* of respondents had access to other nondescript energy resources.

Figure 5.3 shows the reasons given by respondents for not using a specific fuel that was available to them for household cooking.

Figure 5.3: Reasons given by respondents for not using specific fuels for rural household lighting



Reasons given by respondents who had access to paraffin/kerosene but did not use it for household cooking were 'unreliable' *(58.1%, n=18)*, 'unsafe' *(51.6%, n=16)*, 'expensive' *(48.4%, n=15)*, smoky *(16.1%, n=5)* and 'not easily available' *(3.2%, n=1)*.

Respondents chose not use LPG for household lighting despite its availability because it was 'expensive' *(85.3%, n=29)*, 'not easily available' *(32.4%, n=11)* and 'unreliable' *(2.9%, n=1)*. A further 5.9% *(n=2)* of respondents gave other nondescript reasons which included, distribution problems.

'Expensive' and 'unreliable' were the two reasons highlighted by respondents who did use LPG as reasons why they were unhappy using this fuel for household lighting (Table 5.9).

Reasons given by respondents who had access to electricity but did not use it were 'expensive' *(82.2%, n=37)*, 'not easily available' *(11.1%, n=5)*, 'unsafe' *(4.4%, n=2)* and 'unreliable' *(2.2%, n=1)*. Other nondescript reasons were given by 17.8% *(n=8)* of respondents and included the added expense of appliances to exploit energy source.

94.1% *(n=16)* of respondents chose not to use firewood/biomass because it was 'too smoky'. Furthermore, 'unreliable' *(76.5%, n=13)*, 'unsafe' *(76.5%, n=13)* and 'expensive' *(11.8%, n=2)* were reasons also given.

'Smokey', 'unreliable' and 'unsafe' were all reasons respondents who did use firewood/biomass gave for being dissatisfied with it (Table 5.9). 'Health concerns' was also a widely reported reason for being unhappy with this fuel, and could be an underlying factor linked to a concerns surrounding the fuel being 'smoky' and 'unsafe'.

Respondents chose not to use candles for household cooking despite their availability because they were 'expensive' *(50.0%, n=11)*, 'unreliable' *(31.8%, n=7)*, 'not easily available' *(13.6%, n=3)* and 'smoky' *(4.5%, n=1)*. Other non-descript reasons were given by 18.2% *(n=4)* of respondents.

Energy For Heating & Cooling

None of the respondents needed to heat their households during the summer and only one respondent *(1.0%)* heated their house during the winter. Due to the disproportion level of responses the remainder of the questions in this section of the survey have been omitted from the study.

During the winter the majority of respondents *(85.6%, n=83)* did not cool their households and only 14.4% *(n=14)* of respondents did. The time spent cooling households during winter by different respondents ranged from 1.0 to 8.0 hours a day the average being 2.9 hours per day.

During the summer the majority of respondents *(89.7% n=87)* cooled their households. The average time spent cooling the household was 10.1 hours per day, (range 2.5-24.0 hours per day)

Of the respondents who cooled their households, either in the winter or summer, 90.5% *(n=86)* did this through electrically powered equipment (fan, air-conditioning etc.).

Other Energy Usage

Twenty-two respondents *(22.7%)* required other energy resources in order to complete other tasks. These tasks included ironing, running a refrigerator, pumps, heaters, washing machines and televisions.

All of the respondents *(n=22)* who made use of energy resources for additional tasks used of electricity. Two respondents also used other nondescript fuels in order to complete additional tasks.

In total 89.7% *(n=87)* of respondents had access to a source of electrical energy even if they did not use it. The national or state grid supply was the main source, with 97.7% *(n=85)* of these respondents using this to access electricity. In addition, local or personal generators were a source of electricity for 3.3% *(n=3)* of respondents.

The average length of time households have had access to electricity was 8 years 9.5 months (range 2 month-50 years).

5.3.4. Household Fuel Consumption

Each respondent was asked to give details on how much they spend on fuel for household tasks. Table 5.13 provides an overview of the monthly expenditure for each individual fuel and the number of respondents who indicated that their monthly expenditure included said fuel. The same currency conversion rate was used as in Chapter 4 to convert the values given by respondents into pounds sterling, INR = 0.0123 GBP.

Table 5.13: Household expenditure for individual fuels & number of respondent whose monthly expenditure included said fuel

		Number of respondents (%) *(n=97)*	Spend per month (GBP)		
			Mean	Range	
				Min	Max
Household fuel	Firewood	55.7	6.38	0.62	36.92
	Biomass	7.2	3.32	1.23	7.38
	LPG	39.2	4.9	1.35	11.08
	Paraffin/kerosene	64.9	1.16	0.12	14.77
	Electricity	49.5	3.86	0.98	30.76
	Coal	2.1	1.51	1.23	1.85

Paraffin/kerosene, firewood, electricity, and LPG were the main fuels identified by respondents which required monthly expenditure.

Despite a higher number of respondents *(64.9%, n=63)* indicating purchasing paraffin/kerosene, the average monthly expenditure at 1.16 GBP per month (range 0.12 GBP to 14.77 GBP per month) was the lowest out of the four fuels highlighted.

Respondents who used firewood had the highest average spend of 6.38 GBP per month (range 0.62 GBP to 36.92 GBP per month. The average monthly expenditure on electricity was 3.86 GBP and ranged from 0.98 GBP to 30.76 GBP.

Monthly expenditure on LPG ranged from 1.35 GBP to 11.08 GBP per month, with an average expenditure of 4.90 GBP. Total household expenditure per month on all fuels ranged from 0.62 GBP per month to 47.75 GBP per month. With the mean aggregated monthly fuel expenditure being 8.44 GBP per month, per household.

46.4% *(n=45)* of respondents bought all of the fuels they used. 53.6% *(n=52)* obtained some form of free fuel from additional sources. In all cases the ‘free’ fuel was either firewood or biomass or a combination of both, which in the majority of cases was collected from nearby forests or woodland, or was obtained from the livestock kept by the respondent or in the village.

The volume of free biomass used by respondents ranged from 10.0 kg to 400.0 kg a month, with the average being 61.5 kg per month. Respondents who used firewood at no additional cost obtained 67.9 kg of free firewood per month on average (range 5.0 kg to 600.0 kg.

When asked how their fuel usage differed between winter and summer, 25.8% of respondents *(n=25)* increased their fuel usage during winter, and 54.6% *(n=53)* used less fuel in summer. The remaining 19.6% *(n=19)* had no difference in fuel usage.

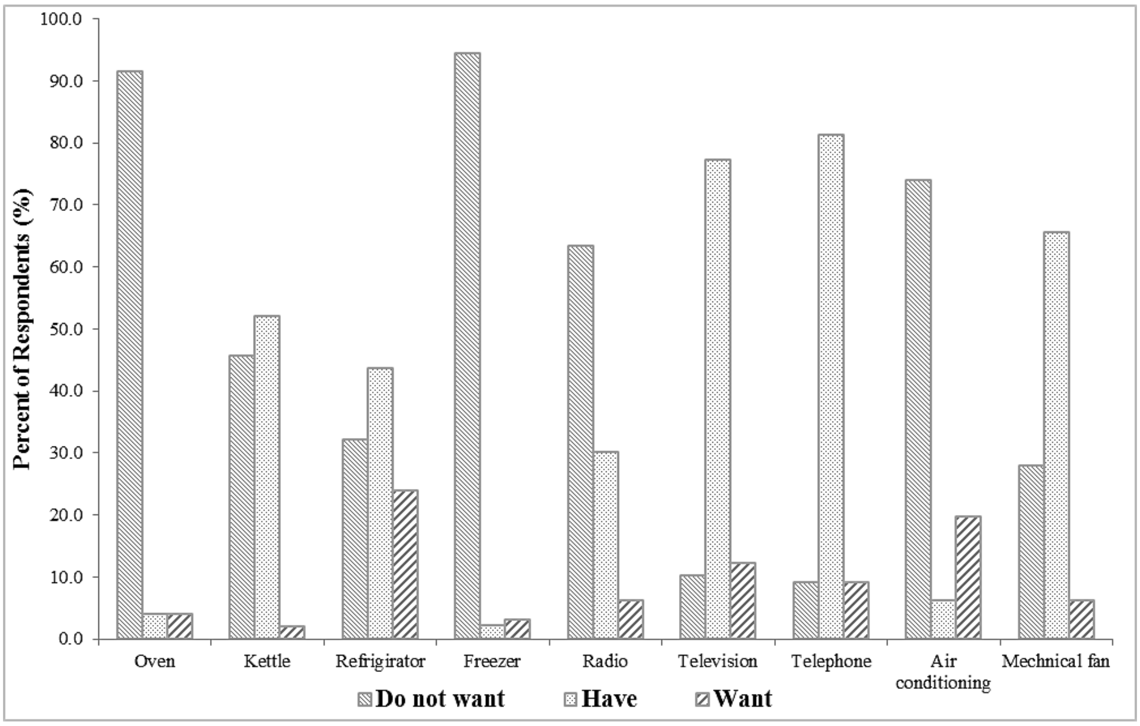
From a list of appliances each respondent was asked which they owned, would like to own or had no interest in owning and if so why. Figure 5.4 shows the opinions respondents had towards the appliances listed. Many household had basic appliances such as a kettle *(52.1%, n=50)*, refrigerator *(43.8%, n=42)*, television *(77.3%, n=75)*, telephone *(81.4%, n=79)* and mechanical fans *(65.6%, n=63)*.

Several of the appliances that respondents did not have, such as an oven, freezer and air conditioning were items the majority of respondents felt they did not need.

Of the respondent who indicated that they did not need an oven, 'expensive' *(57.2%, n=16)* and 'not required' *(39.3%, n=11)* were their reasons. Reasons given for not needing a freezer were because they were 'expensive' *(42.9%, n=12)*, not required *(53.6%, n=15)* and in 7.2%of cases *(n=2)*, the household had no electricity with which to run them. A similar set of reasons were given by respondents for not needing air conditioning; 63.0% *(n=17)* cited expense, 22.2% *(n=6)* 'not required' and 11.1% *(n=3)* the lack of electricity as reasons for not wanting air conditioning.

The most sought after appliances were refrigerators, and air conditioning with 24.0% *(n=23)* and 19.8% *(n=19)* of respondent respectively, wanting these appliances.

Figure 5.4: Respondents position on household appliances.



5.3.5. Household Income & Expenses

In addition to fuel other household expenses included food, transportation, education, clothes, rent and healthcare. Table 5.14 provides an overview of the monthly expenditure for each individual household expense and the number of respondents who indicated that their monthly expenditure included it.

Table 5.14: Household expenditure & number of respondent whose monthly expenditure included noted expense

		Number of respondents (%) *(n=97)*	Spend per month (GBP)		
			Mean	Range	
				Min	Max
Monthly expense	Food	99.0	36.18	3.69	307.64
	Transport	69.1	10.4	1.6	123.06
	Education fees	67.0	10.35	0.15	246.11
	Clothing	72.2	5.65	0.31	246.11
	Healthcare	47.4	6.69	0.74	60.0
	Rent	7.2	16.78	2.46	86.14

The main household expense unsurprisingly was food, with average monthly expenditure being 36.18 GBP per month per household, with a range of 3.69 GBP to 307.64 GBP per month.

Clothing, transport and education were also major household expenses. With 72.2% *(n=70)* of respondents giving clothing as an additional expense it is the second most common household expense. The mean household spend being 5.65 GBP with a range of 0.31 GBP to 73.83 per month.

The number of respondents who gave transport *(69.1, n= 67)* or education fees *(67.0, n=65)* as additional household expenses may be lower than those who gave clothing but the average spend per month for these is almost double that of clothing.

Monthly transport expenditure ranged from 1.60 GBP to 123.06 GBP per month with an average of 10.40 GBP per household per month. The mean education fees were 10.35 GBP per household per month and ranged from 0.15 GBP to 246.11 GBP per month.

Total household expenditure per month ranged from 1.60 GBP to 762.95 GBP per month with the average expenditure being 90.21 GBP per month per household.

164 household members (7 females, 157 males) contributed to the household income through paid employment.

The number of people per household engaged in paid employment, in order to generate some form of income for the household, ranged from 7.1% to 80.0% of total permanent household occupants. Having a single person *(45.7%, n=42)* contributing to the household income was the most common occurrence, with the average being 1.6 people per household.

The proportion of male and female household members working also varied. Only 7.8% *(n=7)* of respondents indicated that female household members were contributing to the household income through paid employment. In all of these cases only a single female per household was employed.

Almost all of the respondents *(97.8%, n=89)* indicated that at least one male in the household was employed and contributing to the household income. The most common number of males employed was 1 per household *(48.4%, n=44)*, the average being 1.6, ranging from 1 to 5 males per household in paid employment.

The average combined total number of hours worked was 80.3 hours per week per household, and ranged from 21.0 hours to 400.0 hours per week.

The number of hours worked per week varied depending on gender; male household members worked on average 52.0 hours, whereas female members worked on average 45.5 hours per week. The number of hours worked by males also had a larger range (14.0 to 135.0 hours per week) than the number of hours worked by females which was more narrow (range 35.0 to 56.0 hours per week).

As well a variation in the number of hours worked by male and female members of households, there was also a difference in the weekly wages between the two genders.

Male incomes ranged from 1.11 GBP to 73.83 GBP per week, with 14.51 GBP per week being the average male income. Female weekly income ranged from 4.92 GBP to 61.53 GBP per week; on average women earn 23.4% less than men, with their average weekly income being 11.11 GBP.

The average total household income was 23.88 GBP per week, and ranged from 1.23 GBP to 147.67 GBP per week.

In addition to paid employment, 12.4% *(n=12)* of respondents, indicated that their households also had additional income from other sources including state and private pensions. The average additional income was 39.20 GBP per month per household (range 1.03 GBP to 270.73 GBP per month).

In addition to the time spent working, each respondent was asked to detail the amount of time different members of the household spend completing other tasks when not working, such as collecting water and cooking. This was done in order to gain a more complete picture of how time is utilised in the household and in particular by which members, and where modern energy services might help free up time for other productive activities.

The time spent on additional activities by a total of 184 individuals (95 females and 89 males) were outlined. Only a single male spent time collecting water. For 7 hours per week. Of the 95 females, 58.9% *(n=56)* spent on average 7.4 hours per week collecting water (range 1.0-50.0 hours per week).

Forty females *(42.1%)* spent time collecting firewood or biomass (range 5-50.0 hours per week). Fewer males spent time collecting firewood or biomass, *(8.4%, n=8)*, and ranged from 3.0 to 30.0 hours per week, with the average being 9.0 hours per week.

No time was spent by males cooking, and only for five females was cooking cited as an additional task that they completed, on which an average of 21.7 hours per week was spent (range 14.0-28.0 hours per week).

The average time males and females spent in education were similar with males spending on average 35.0 hours per week (range 5.0-115.0 hours per week) in education and females an average of 37.0 hours per week (range 8.0-56.0 hours per week).

More men spend time on recreational activities than women. Of the ninety-five males 56.7% *(n=51)* partook in some form of recreational activity, whereas only 38.9% *(n=37)* of women indicated doing so.

However, the average time spent on recreational activities was less for men, 19.0 hours per week (range 2.0-50.0 hours per week) than for women, 26.0 hours per week (range 5.0-56.0 hours per week).

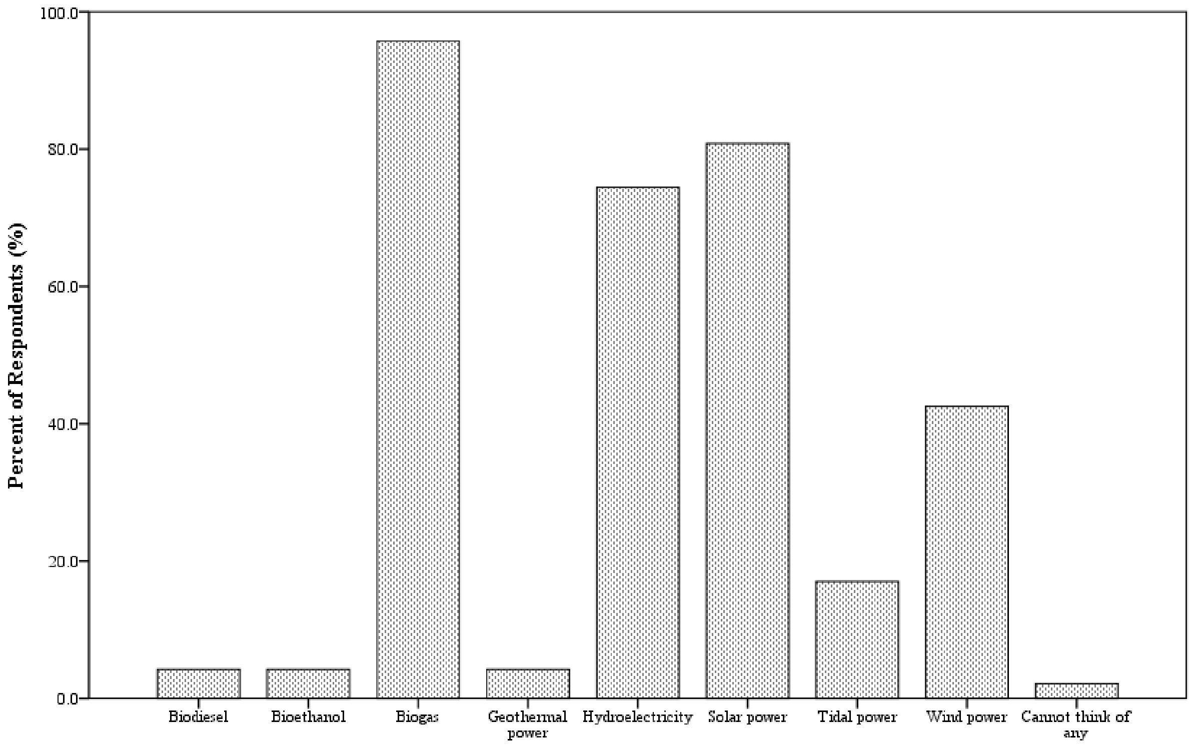
Other nondescript activities were identified by 2.1% *(n=3)* of men and 4.2% *(n=4)* of women and on average accounted for 9.9 hours per week in men and 11.8 hours per week in women.

5.3.6. Respondent's Views On Renewable Energy

When asked if they were aware of the term 'renewable or sustainable energy', 48.5% *(n=47)* of respondents were aware. The remaining 51.4% *(n=50)* were not. Of the respondents who were, only 38.3% *(n=18)* provided their definition of what they believed these to be. Twenty-seven respondents *(57.5%)* did give or did not want to give a definition, and a further 4.3% *(n=2)* of respondents had insufficient knowledge to provide a definition.

Figure 5.5 shows the different examples of renewable energy resources that respondents who were aware of the term could identify. Biogas was the most popular example given, with 95.7% *(n=45)* of respondents identifying it. Solar power and hydroelectricity were the next examples frequently cited with 80.9% *(n=38)* and 74.5% *(n=35)* of respondents identifying them respectively. Only one respondent could not think of any examples.

Figure 5.5: Renewable energy resources identified by respondents who indicated prior awareness of the term.

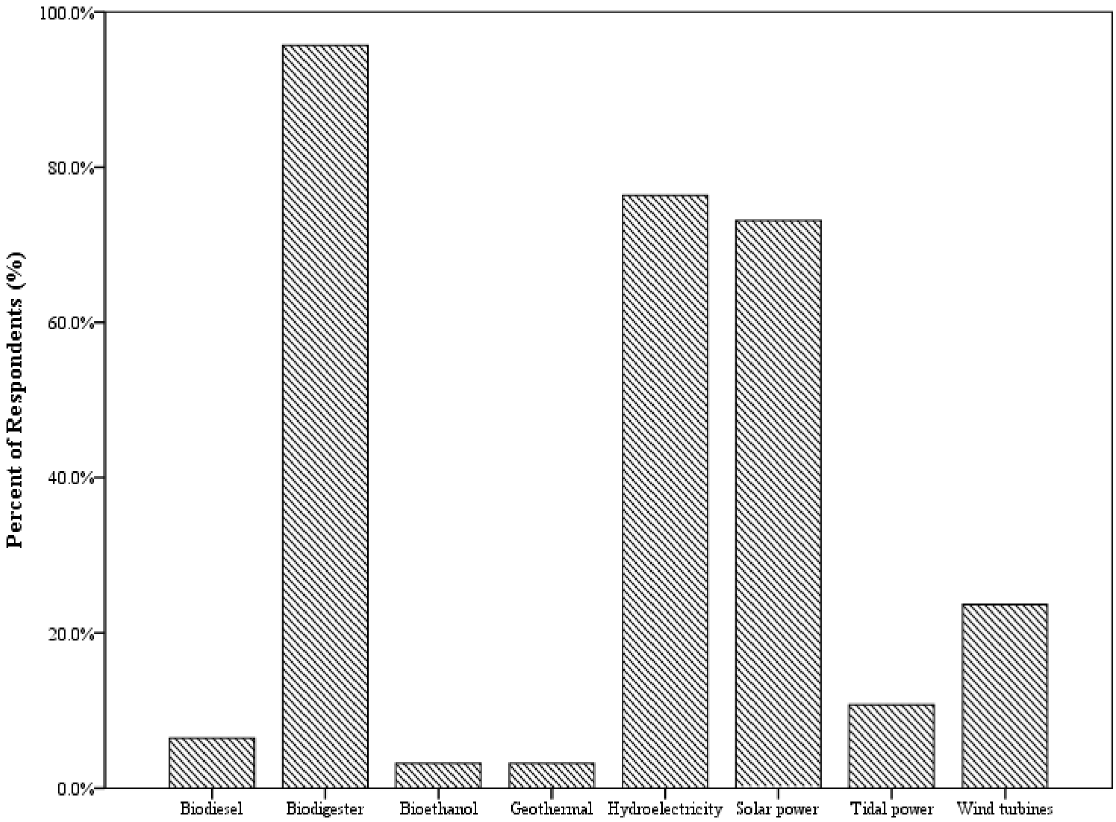


All of the respondents, including those who were unaware of the term renewable or sustainable energy, were asked to identify which technologies for the generation of low carbon energy they were aware of from a given list, see Figure 5.6.

Bio digesters were the most widely recognised technology with 95.7% of respondents *(n=89)* identifying them. Hydroelectricity and solar power where the next two most recognised means of energy generation with 76.3% *(n=71)* and 73.1% *(n=68)* of respondents respectively selecting them.

All of the respondents had heard of at least one technology. Unsurprisingly the pattern of technologies recognised by respondents mirror the renewable energy resources identified (Figure 5.5). Respondents are thus aware of a select group of technologies available for low carbon energy production even if they were unaware that they are renewable or sustainable energy resource.

Figure 5.6: Low carbon technologies used for energy generation recognised by respondents.



The respondents were provided with a brief overview of each of the technologies before they were asked to indicate which they believe (if any) would be of most benefit if used as a means of delivering modern energy services to their household or village.

The energy resources respondents identified those that they believed would be of most benefit to their village or household included biogas *(74.2%, n=69)* and solar power *(64.5%, n=60)*. Only 5.4% *(n=5)* of respondents thought that hydroelectricity or wind power would provide any benefit. Only 19.4% *(n=18)* of respondents did not think any of these energy resources would be of any benefit. Of this 19.4%, 55.6% *(n=10)* had previously indicated that they were unaware of the term renewable or sustainable energy.

The reasons given by these respondents for why they believed these sources of energy would be of no benefit included a lack of interest and scepticism due to previous negative experiences combined with a lack of faith in the government to help set-up and maintain equipment for a long term and reliable supply. Some respondents believed the technology and subsequent supply would be too expensive for them to afford and impractical to meet their energy needs, others simply believed these technologies would provide no additional benefits over their current supply.

The main reasons given by respondents who believed that solar power would be a beneficial energy resource was because there is an abundance of sunlight available for most of the year and because of this energy production would be at a cheaper cost to them as a user. Some respondents believed that a single payment for set-up costs would also lead to a cheaper energy supply. Other respondents indicated that the benefit of using solar power would mean not having to use non-renewable energy resources that were harmful to the environment.

Respondents also identified biogas as an energy resource they believed would provide benefits to their household or village. There is an abundance of feedstock available as most people own some form of livestock. Because of the availability of feedstock, some respondents believed that the cost of using this as a source of energy would be cheaper and easy to implement. Some respondents highlighted environmental benefits as their reason for selecting this resource as they believed it would mean using less non-renewable energy resources.

Despite highlighting the energy resources they believed would provide the most benefit to their household or village, 76.8% *(n=73)* of respondents had no preference towards one energy source over another. Of the 23.2% *(n=22)* that had a preference, 57.2% *(n=12)* of respondents gave solar power as their preferred energy resource, giving reasons such as low maintenance, low set-up and operating costs for their choice. Biogas was cited by 47.7% *(n=10)* of respondents as their preferred energy resource, giving availability of feedstock, ease of use and easy to maintain as their reasons.

The vast majority of respondents *(90.2%, n=83)* indicated that in their opinion communities like their own should be provided with these types of alternative energy supplies. When asked if these alternative energy resources should be used over current means of energy provision 72.8% *(n=67)* of respondents thought they should.

64.0% *(n=16)* of the respondents who did not want alternative energy sources to be used over current supply did however believe that their communities should be provided with these alternative energy supplies.

Reasons given by those respondents for why they thought alternatives should not be used over current means of energy provision included concerns surrounding reliability and availability as well as being more comfortable using a fuel that is familiar to them.

Similar reasons were given by respondents for why these alternatives should be used. They believed they will provide a more reliable supply that would be cheaper and more affordable, making it more accessible. Many respondents also believed these types of alternatives should be used because of the environmental benefits they offer such as reduced pollution.

Respondents were asked a series of questions to see how cost would affect their choice to switch from their current energy supply to an alternative low carbon one, despite any benefits that could be gained by switching.

When the cost of using these alternatives was the same as their current supply, 85.3% *(n=81)* of respondents would switch if they knew switching was helping protect the local environment. If switching led to a safer and more reliable supply 89.5% *(n=85)* of respondents would switch. Only 9.5% *(n=9)* of the respondents would not switch if they knew it was helping protect the local environment or if it led to a safer and more reliable supply.

If switching meant paying slightly more than their current energy supply, 43.8% *(n=42)* of respondents would switch if they knew it would be helping protect the local environment. Furthermore 44.8% *(n=43)* of respondents would also switch for a safer and more reliable supply even if it meant having to pay more.

Of the respondents that would switch to help protect the local environment when the price stayed the same just over half *(51.9% n=42)* would still switch when the price was slightly higher. Of those who would switch when the price was the same and it meant a safer more reliable source of energy, 50.6% *(n=43)* would still switch even if it meant paying slightly more for these same benefits.

To ascertain what factors would influence a respondent's choice to contribute to the set-up costs of a renewable or sustainable energy supply each was asked if they would contribute if it meant either a cheaper supply, more reliable supply or a safer supply, Figure 5.7.

72.9% *(n=70)* of respondents would contribute towards the set-up costs for a cheaper supply, 35.4% *(n=34)* for a safer supply and 37.5% *(n=36)* of respondents would contribute towards set-up cost for a more reliable supply.

When comparing the answers respondents gave to this and the previous set of questions (Table 5.15), of the respondents who would switch energy supply if it were the same price but also meant a safer and more reliable supply, 42.4% *(n=36)* would also contribute towards the set up costs for a more reliable supply and 40.0% *(n=34)* would contribute for a safer supply.

Of the respondents who would switch and pay slightly more for an energy supply that was safer and more reliable, 74.4% *(n=32)* would also contribute for a safer supply and 79.1% *(n=34)* for a more reliable.

In addition 96.2% *(n=51)* the respondents who would not switch energy supplies if it meant paying slightly more (even if it meant a safer and more reliable supply) would also not contribute towards the set-up cost even if it meant a safer or more reliable supply.

Figure 5.7: Factors affecting whether respondent would contribute to the cost of setting up a renewable or sustainable energy supply.

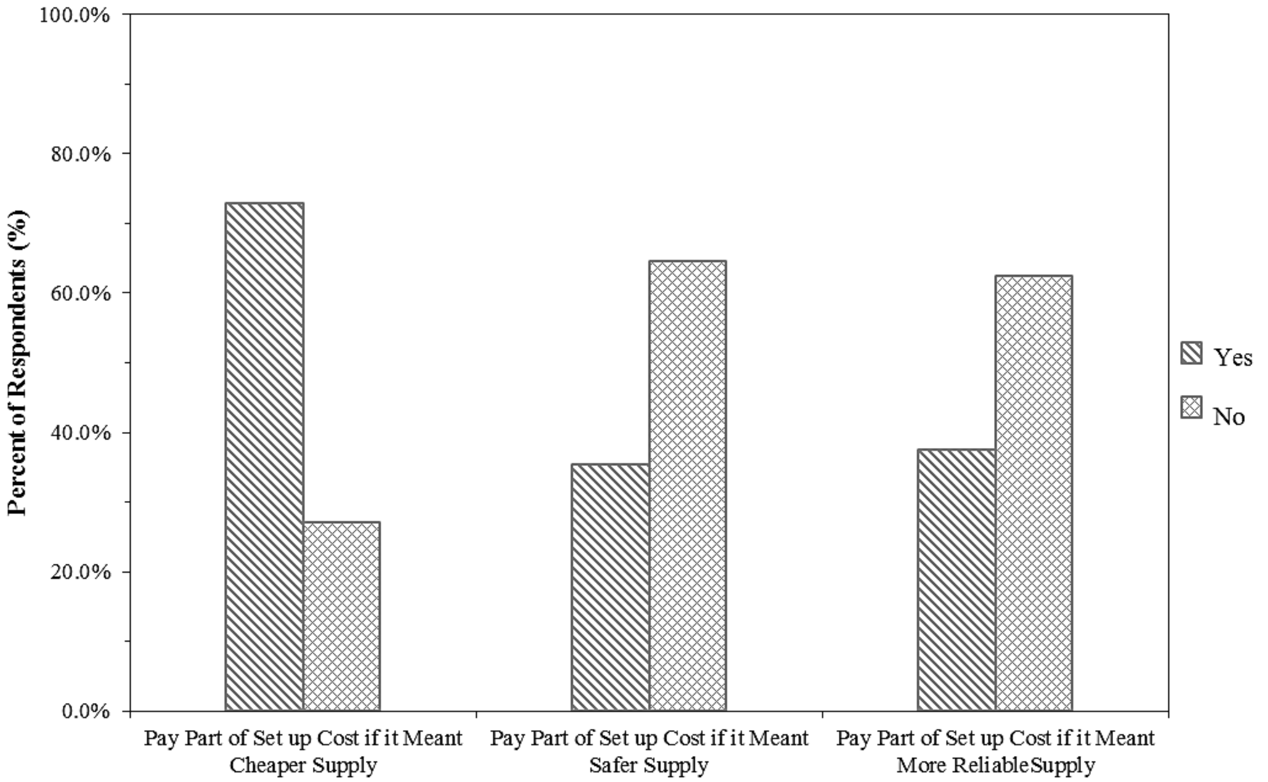


Table 5.15: Comparison of the affects incentives have on a respondent's willingness to switch to, or contribute towards a renewable or sustainable energy resource

			Switch if same price & was safer and more reliable (%)		Switch if slightly more expensive but was safer & more reliable (%)	
			No	Yes	No	Yes
Pay part of set up cost of renewable or sustainable energy supply if meant:	Cheaper supply	No	40.0	24.7	43.4	7.0
		Yes	60.0	75.3	56.6	93.0
	Safer supply	No	100.0	60.0	96.2	25.6
		Yes	0.0	40.0	3.8	74.4
	More reliable supply	No	100.0	57.6	96.2	20.9
		Yes	0.0	42.4	3.8	79.1

It is clear from these results that when it comes to selecting a fuel resource for household activities, cost is the most important factor. When removed (as shown when the energy resource price stayed the same as their current supply) respondents were more willing to switch to an alternative renewable or sustainable supply in order to gain the benefits of switching such as increased reliability and safety, and reduced environmental impacts.

Several incentives were identified by respondents that would encourage them to adopt the use of renewable or sustainable low carbon energy sources. In particular financial support from the government or NGOs was identified as a means to fully or partially fund projects to help reduce overall costs, as well as continuing support through maintenance and subsidies to ensure a cheap energy supply. Many respondents felt that these technologies should be provided to them for free by the government.

Consulting with those in the community to improve awareness of the alternatives that are available and the benefits that could be gained through their use as a source of energy, such as improved reliability, reduced environmental impacts and cheaper energy supply would help encourage their acceptance and uptake.

Other respondents wanted to see these types of energy project as part of a wider development plan. Many would also like to see projects that would create jobs within the local community, especially by giving them control over the projects once completed by entrusting the responsibility of maintenance and repair to those within the community.

Several issues were highlighted by respondents as potential problems that might be observed during the set-up and operation of an alternative renewable or sustainable energy supplies which could threaten its success.

Obstacles that might be experienced during the set-up included issues surrounding a shortage of available land for the necessary equipment to be installed with 38.1% *(n=37)* of respondents citing this a likely problem. In addition 21.9% *(n=29)* of respondents believed that the high costs and lack of available funds could also cause problems during set-up. Corruption and lack of infrastructure were highlighted by 7.2% *(n=7)* and 5.2% *(n=5)* of respondents respectively. A lack of knowledge and understanding was also noted by 3.1% *(n=3)* of respondents as another potential barrier to overcome during set-up.

Problems that respondents thought might be experienced during the operational phase, once set-up is complete, included a lack of government support *(7.3%, n=7)*, maintaining the energy supply and keeping it operational *(22.9%, n=22)* and corruption *(8.3%, n=8)*. Some respondents voiced concerns that the cost of the energy supplied would be too high making it unaffordable thus unavailable to many members of the community it is aimed at serving.

5.3.7. Archetypical Household From Rural Orissa

From the results gathered it is possible to build a picture of a typical rural Indian household. This can then be used to model the socioeconomic and environmental effects of varying future energy demands and the means used to meet any increased demand.

A summary of a standard Indian household, as based on the survey results is as follows:

Household:

- Has 6 permanent occupants.
- The head of household is a male, but females are responsible for deciding on the fuels used in the household.
- The household is a single story building consisting of 4 rooms with two entrances and 3 windows, which are left open all the time.
- These are built using standard bricks with concrete for the roofing and cement for the flooring.
- They do not grow their own crops but keep at least one cow.

Energy usage:

- Non-natural lighting is used in the evenings for 5 hours in the winter and 5.1 hours in the summer.

- Electricity is used as a main energy source for non-natural lighting, with paraffin/kerosene an additional source.
- Fuel lamps and electric light bulbs are used as a means of generating light with the household using 2 fuel lamps which consume 0.1 litres of fuel per day each and 5 light bulbs which are 20 watt energy saving light bulbs.
- Electricity is available from the main national or state grid supply.

- 2.5 hours per day are spent cooking.
- Firewood or biomass is used as the main energy resource for household cooking, and paraffin/kerosene is used as an additional source.
- 124.7 kg of firewood or biomass is used per month along with 3.2 litres of paraffin per month.

- 10.1 hours per day is spent cooling the household during summer via electrically powered equipment.

Amenities:

- The household owns at least one kettle, refrigerator, television, telephone and mechanical fan.

Finances:

- The total household expenditure per month (excluding fuels) is 62.58 GBP.
    - 36.18 GBP per month of food.
    - 10.40 GBP per month on transport.
    - 10.35 GBP per month on education fees.
    - 5.65 GBP per month on clothing.

- There is a total household income of 116.08 GBP per month.
- 2 people contribute to household income, both of which are males. Each work on average 52 hours per week earning 14.51 GBP per week per person.

Fuel expenditure:

- The total monthly fuel expenditure is 14.72 GBP per month.
- 6.38 GBP per month is spent on firewood, 3.32 GBP per month on biomass, 1.16 GBP per month on paraffin/kerosene and 3.86 GBP per month on electricity.

- 65.68 kg of firewood/biomass is acquired for free.
- The fuel usage increases in summer compared to winter.

Use of non-work time:

- Female members of the household spend 7.4 hours per week collecting water, 15.4 hours per week collecting firewood or biomass, and 26.0 hours per week on recreational activities
- Male members of the household spend 19.0 hours per week on recreational activities.

5.4. Discussion

Use Of Fuels In The Home

In this study the respondents were happy with their electricity source despite having to make use of alternatives due to power cuts suggesting that this is not seen as negative characteristic of the energy source and is simply to be expected with its use.

Electricity is generally considered to be one of the most reliable energy sources, particularly in western countries. However, in the Indian electricity sector there are consistently shortages at peak times and there have been instances of widespread and prolonged blackouts (Shukla *et al.* 2009, Szakonyi & Urpelainen 2013). Within this context it may explain why these respondents did not consider power cuts a negative characteristic and why they are happy with electricity as a source of household energy as power cuts are merely accepted as an aspect of the fuel.

LPG and firewood/biomass were the two main primary fuels used for household cooking. Both groups of respondents who used these fuels did because they were easily available and easy to use. However, respondents who used firewood/biomass also gave ‘cheap’ and ‘cannot afford other fuels’ as reasons.

Nearly all LPG users were happy using this energy source whereas the majority of those who used firewood/biomass were not. With too smoky, health concerns and safety being the reasons given for being dissatisfied. These are valid concerns when you consider that the level of smoke produced by the burning of firewood/biomass has been identified as a major health risk. The US Environmental Protection Agency outlined a 150µg m^{-3} safety limit on particular matter to maintain ‘good health’. In many Indian household this level can exceed 2000µg m^{-3} as a result of using firewood/biomass for cooking (IEA 2007, Smith 2000). This can often mean localised air pollution can occur during peak cooking times. As a result, acute respiratory infections are now the largest single disease category in India (IEA 2007)

The use of RETs would have a significant impact on reducing this pollution thus could lead to significant health benefits in addition to those already obtainable through the provision and use of modern energy services.

The majority of respondents (including those who were happy with their primary cooking fuel) made use of at least one additional fuel source for cooking. Paraffin/kerosene and firewood/biomass were the main additional fuels used by respondents whose primary energy source was LPG. ‘Primary fuel unavailable’ was the main reasons for using additional resources.

Due to a flaw in the questionnaires design the definition of ‘availability’ is unclear. It may refer to the ability to physically source the fuel or their ability to be able to afford it. However, as the majority of LPG users indicated they used it because it was ‘easily available’ it is most likely the later reason. Evidence to support this comes from previous studies which have shown that the use of LPG as a primary fuel for household cooking in rural areas is restricted to households with higher incomes (Balachandra 2011a, Pohekar *et al.* 2005, Rao & Reddy 2007). Balachandra showed that the use of paraffin/kerosene and firewood/biomass for household cooking was more common in lower income households (Balachandra 2011a). It is therefore plausible that when the use of LPG becomes unaffordable these households switch to the cheaper alternatives that are also easily available.

Respondent who used firewood/biomass for cooking were more likely to have used paraffin/kerosene as an additional fuel source or indicate that they did not use any other additional fuel sources. It is reasonable to conclude that because these respondents gave ‘cheap’ as their main reason for using their primary fuel that they cannot afford to use some of the fuels that are available. Those that did use alternatives did so but under specific circumstances as they could not afford to use them continuously as their high cost made them an unaffordable solution for energy provision. The respondents who did not use any additional energy sources simply may be unable to afford those that are available therefore have to make do despite any grievances.

This study has shown significant differences compared with previous studies in the extent certain fuels were used for rural household lighting and cooking (Balachandra 2011a, Blenkinsopp *et al.* 2013). Balachandra (Balachandra 2011a) found that 84.1% of households made use of firewood/biomass and only 8.6% of LPG as their primary fuels for household cooking. Furthermore electricity was used by 55.0% of households and paraffin/kerosene by 44.0% for household lighting.

Although the fuels used are comparable, the degrees by which they are used are very different. This disparity may be the result of the differences in data sets used. This study as outlined in the methodology explores the energy usage of thirteen villages were as Balachandra's study is based off of national statistics for the whole of India.

Paraffin/kerosene was used by nearly every respondent *(92.8%, n=90)*. However, it is mainly used as an alternative energy resource, with 82.5% *(n=80)* of respondent using it solely for this purpose. It was also the main alternative used in both cooking and lighting. The hazards associated with the use of paraffin/kerosene as a household fuel have been widely documented (Epstein *et al.* 2013, Lam *et al.* 2012, WHO 2009). It could be these hazards; which include poisoning, explosions, fire, low birth weight, increased risk of respiratory problems and cancer, which deter the use of this energy resource which is why it is only used by respondents when absolutely necessary.

The study showed that household fuel usage was lower in winter months than summer. This is most likely because the majority of households did not have to cool their houses during the winter. This may mean during the winter periods the households have a larger disposable income or more flexibility in their budgets as they are spending less on fuels.

Respondents who used electricity and/or LPG as their primary energy source for household cooking or lighting gave very similar reasons for why they chose to use these two fuels, (these being mainly centred on their availability and ease of use) and why they used alternative energy sources in addition to them (centred on the inconsistency of their availability). In addition the small number who were unhappy using these energy sources also gave the same reasons for being dissatisfied, these reason relating to cost and reliability.

This is interesting as both of these fuels are considered modern forms of energy (Balachandra 2011a), but despite being very different resources, the reasons for why respondents used them and the issues they had with them are the same. It could therefore be implied that there is a set of common motives and issues associated with the procurement and use of modern energy resources in rural communities.

The results highlighted availability and ease of use as two important factors when selecting fuels for household tasks. 'Easily available' *(87.6%, n=85)* and 'easy to use' *(95.9%, n=93)* were the main reasons respondents gave for their choice in using one or more energy resource. In addition they were the only reasons to be highly selected as influencing factors across all the major fuels used for household cooking or lighting.

Previous studies have highlighted accessibility as an important barrier to modern energy access and the uptake of RETs (Painuly 2001, Reddy & Painuly 2004). RETs however, have been shown to lend themselves to being used as decentralised energy resources. This means energy generation can be put at the heart of a community avoiding many accessibility barriers (Chakrabarti & Chakrabarti 2002, Hiremath *et al.* 2009, Mahapatra & Dasappa 2012).

The cost of a fuel also appears to be an important factor in fuel selection, with it being the main influencing factor given by respondents for choosing to use firewood/biomass. It also appears to affect a respondent choice when selecting fuels to use in addition to their primary resource. Cost it appears is the limiting factor when it comes to fuel selection, with the majority of respondents' fuel selection determined by what they could afford. If cost was removed as a factor it is highly likely that we would observe a very different composition of the energy resources used.

The cost of installing and operating RETs has been highlighted extensively as a potential barrier to their uptake and long term success, in particular if these costs are passed on to the end users which can lead to RETs becoming an unaffordable solution for energy provision (Mitchell *et al.* 2011, Painuly 2001, Rady 1992, Reddy & Painuly 2004). It has been noted however, that the use of these technologies as decentralised energy resources can ultimately lower the costs to the end user as they reduce, if not avoid, many of the costs relating to energy transportation and distribution as they can be installed close to the point of demand (Chakrabarti & Chakrabarti 2002, Thiam 2010).

Reliability also appears to be an important factor when it comes to fuel selection. Factors relating to reliability were the main reasons respondents gave for making use of additional energy sources for cooking and lighting over their primary resource. In addition 'unreliable' was also one of the main factors highlighted by respondents who indicated being unhappy with their main fuels for cooking and/or lighting.

However despite reliability issues, the majority of respondents were happy with their primary energy resources. From this it is reasonable to surmise that although reliability was not a characteristic specifically desired by the majority of respondents it was however an important factor which affected the number energy resources used and the extent by which they were utilised.

Del Río (Del Río 2007) and Painuly (Painuly 2001) both identified that a lack of technical knowledge and skilled personnel for setting up and operating RETs in developing countries can affect their long term success and can lead to performance issues. With reliability being an important factor this is an important barrier which must be overcome if the introduction of RETs is to be successful and not lead to negative attitudes.

Perception, Attitudes & Barriers Towards Renewable Or Sustainable Energy Sources

Prior to this study less than half of all respondents were aware of the term renewable or sustainable energy, even fewer were aware of what the term actually meant. A lack of knowledge is the primary barrier to the adoption of any new technology. A lack of technical knowledge and awareness in RETs has been identified as a potential barrier to their uptake (Del Río 2007, Reddy & Painuly 2004).

All of the respondents, even those who indicated they were unaware of the term renewable or sustainable energy, had heard of at least one example of renewable or sustainable energy sources from a given list. However, even after being given a brief overview of the different technologies only those which had been previously recognised by respondents where then identified as potentially being a beneficial energy source.

The respondents who did not believe any of these energy sources would be of benefit gave reasons such as previous negative experiences, lack government support and the expense, all of which have been identified as barriers to the uptake and long term success of RET projects (Del Río 2007, Mitchell *et al.* 2011, Moomow *et al.* 2011, Painuly 2001).

Despite having highlighted the energy sources they believed would provide most benefit the majority of respondents had no preference towards one energy source over another. This may be the result of a lack of knowledge and understanding of the technologies and of the impacts and benefits associated with them. Despite this the majority of respondent believed communities such as their own should be provided with renewable or sustainable energy supplies, and that they should be used over their current means of energy provision.

The reasons respondents gave for why these alternatives should be used (accessibility, more affordable and more reliable) corresponded with the main factors highlighted as important in influencing their choice of energy resources they currently used. In addition the environmental benefits of the resources were also given by some respondents.

Acceptance has been highlighted as a vital factor through several studies (Moomow *et al.* 2011, Painuly 2001) for the implementation of RETs. Without it the likelihood of a successful project is reduced, which itself can damage the perception of RETs further, resulting in additional barriers to any future projects. A factor which was observed in this study.

Overcoming these barriers can be achieved by establishing dedicated lines of communications from an early stage of planning between planners and stakeholders (Moomow *et al.* 2011). The inclusion of public participation into planning decisions and by educating the target population of the long and short term benefits of using such technologies for energy generation should greatly improve their acceptance and successful implementation.

This study showed that when it comes to selecting an energy resource for household activities cost is the most important factor. It is also the biggest barrier to the implementation of RETs in rural Indian villages. As seen with the selection of fuel resources for household activities cost is an important limiting factor which influenced a respondent’s choice to switch to an alternative renewable or sustainable energy supply or contribute towards their set up.

The benefits of switching to a renewable or sustainable energy supply were insufficient on their own to persuade a respondent to switch. Only when cost was removed as a factor, when the energy resource price stayed the same as their currently supply, were respondents more likely to be swayed to switch by the benefits.

The desire for reducing the long term costs of energy provision were shown by the fact that the majority of respondent were willing to contribute to the set up costs of a supply that ultimately led to a cheaper supply. The importance of cost was further highlighted as respondents indicated that significant incentives which would encourage them to use renewable or sustainable energy supplies would be subsidies to ensure a cheap supply and financial support for the set-up and ongoing operation of RETs from the government or NGOs.

Furthermore respondents highlighted concerns relating to the high costs of set up, lack of available funds as well as the final cost of the energy supplied as problems which might be experienced during the set up and operation of these energy sources and could threaten their long term success.

Gurung *et al.* (Gurung *et al.* 2011), Painuly (Painuly 2001) and Reddy & Painuly (Reddy & Painuly 2004) highlighted that the high costs associated with RETs are one of the major barriers to their successful implementation. These high costs can often restrict access to these technologies as they become an unaffordable solution for energy provision. The need to improve infrastructure in many developing countries can also add additional costs to RET projects. These costs may well be passed onto the consumer which can lead to problems of uptake when the costs start to exceed those in comparison to more conventional means of energy provision (Mitchell *et al.* 2011, Painuly 2001). This is seen in the study where the willingness of respondents to use renewable or sustainable energy sources is influenced by the associated costs.

Several studies (Mitchell *et al.* 2011, Painuly 2001, Reddy & Painuly 2004) have noted that increased uncertainties and a lack of confidence in a project can contribute to increased costs and threaten long term viability. This in turn can make attracting funding from financial and private investors difficult as they are often reluctant to provide funding for small scale projects that are associated with such risk. This can therefore make it almost impossible for people on low incomes to invest in RETs.

In addition the need to invest heavily in technical expertise and infrastructure, particularly in rural areas, can deter investors often leaving these areas isolated from sustainable development. However by evaluating the needs and attitudes of target communities many barriers can be overcome by using the appropriate energy resource to meet their needs, and by communicating with stakeholders from an early point.

This study found that there is significant interest in the use of renewable or sustainable energy sources over more traditional means of energy generation. There are however a range of barriers to overcome to ensure their successful implementation.

The energy provided via these energy sources must be easy to use, easily available and affordable as these were the most important characteristics identified by respondents which influence their selection of fuels. Reliability was also identified as an important factor as not only did it effect fuels use but has also been shown to be a significant barrier to the long term viability of RET projects.

Overall the most important factor is ‘affordable’, as it is the costs associated with an energy source which determines the extent of their uptake and long term success.

5.5. Summary

The current energy requirements of India’s rural communities were explored in this study using a household survey, and a summary of a typical household’s energy requirements outlined.

The results showed that the main areas for energy demand are lighting, cooking and cooling of the household. With the criteria for fuel selection centred on ease of use and availability. Cost was also shown to be an important limiting factor. Furthermore households used more than one energy source to meet their demand from these areas, with availability and reliability being the main issues for having to use multiple energy sources.

As these households did not have access to reliable or affordable energy sources for cooking and lighting, they cannot be regarded as possessing modern energy access, as they do not satisfy this studies definition. There is therefore still capacity for the expanded use of alternative modern energy sources to delivery modern energy access.

The attitudes of these communities towards more sustainable means of energy generation were also explored using the household survey. There was a lack of fundamental knowledge and understanding surrounding renewable or sustainable energy but not in awareness of the technologies that exist. Despite this there was interest in using these energy sources over more traditional means. There are however a range of barriers that need to be overcome. The incentives of using these energy sources were insufficient alone to persuade respondents to switch to or contribute towards their setup. They must meet the criteria previously set out for fuel selection whilst also providing an affordable and more reliable energy supply. Although cost is likely the most important factor affecting uptake, reliability was shown to be a significant barrier to their long term viability.

The finding of this study broadly agree with those observed in Chapter 4, with similar criteria and limiting factors for fuel selection being identified. In additional despite interest in the use of RETs being identified in both studies, both also outlined that on their own there is insufficient incentive for their uptake. The similarities and differences of these two studies will be discussed in more detail later in this thesis.

Chapter 6. Identifying Socio-Economic Factors That Affect Respondents' Attitudes Towards Renewable Energy Sources In The Indian State Of Orissa

6.1. Introduction

The previous chapter highlighted potential opportunities for and barriers that existed to the expanded use of renewable energy sources for decentralised energy generation. Many of these barriers can be associated with certain attitudes. This chapter aims to explore respondent attitudes towards alternative, more sustainable means of energy provision via renewable energy sources in order to identify factors associated with these attitudes. These in turn could then be used to target groups with similar attitudes enabling action to be taken to improve the acceptance and uptake of RETs by reducing the barriers to their use.

In this chapter, the attitudes towards the acceptance of RET projects are explored. Acceptance is one of the main barriers to the uptake and use of RETs. The long term success and viability of an RET project can be weakened by a lack of acceptance in a target community (Moomow *et al.* 2011, Painuly 2001). Without acceptance, the feasibility of a project is lessened.

There however a range of socioeconomic factors which could affect a respondents' attitude towards the uptake of these technologies, such as education, age and household income.

Moula *et al.* (2013) showed the age of respondents affected the likelihood of them accepting an RET, with older respondents being more supportive of the use of RETs (Moula *et al.* 2013). Age was also shown to be an important factor that affects awareness of RETs in several other studies (Karytsas & Theodoropoulou 2014, Stigka *et al.* 2014). Stigka *et al.* (2014) and Moula *et al.* (2013) both showed that household income was positively correlated with people's willingness to support the use of RETs, and education has been highlighted as an important factor for improving the uptake of RETs in several studies (Bhide & Monroy 2011, Jennings 2009, Kandpal & Broman 2014, Stigka *et al.* 2014).

A community's attitude can also be an opportunity to expand the use of RETs. There is obviously a need to meet energy demand in any community, but the desire of a community to utilise RETs to meet this demand provides an opportunity for RET exploitation.

These factors which are associated with certain attitudes could be used as indicators to better understand how to introduce these technologies and help avoid or overcome some of the barriers by allowing targeted action to be taken against groups or individuals from particular backgrounds. This approach has been demonstrated in several areas where a product or service is design or tailored to maximise its penetration and appeal to the intended audience (Menegaki 2012, West *et al.* 2010).

6.1. Methods & Approach

This chapter uses the results gathered from the rural energy survey described in the previous chapter, the methodology and approaches for the surveys design and how the data was collected and subsequently analysed can be found in Chapter 3.1.

6.2. Results & Discussion

6.2.1. Factors Affecting Awareness Of Renewable Or Sustainable Energy Sources.

Outcome Variable 1: Aware of the term renewable or sustainable energy?

The results of the binomial logistic regression using outcome variable 1 are presented in Appendix 1, Section A.1.1.

Respondents from the village of Tamando were significantly *(p=0.02)* more likely to be aware of the term renewable or sustainable energy than those who were not. Respondents from the village of Dadhapatna were significantly *(p=0.03)* less likely to be aware of the term renewable or sustainable energy. The village of Dadhapatna was the only village surveyed from the Cuttack region which would explain why respondents who were from this district were found to be significantly less likely *(*p=0.03*)* to be aware of the term renewable or sustainable energy from those from the Khordha district. It is not however clear whether the reasons they are unaware of this term is related to them being from this specific village or whether it is wider lack of awareness across the district as a whole. This lack of awareness may be linked to the level of education; the literacy rates in Khordha are higher than Cuttack. Only 53.0% of Cuttack's population have attained an education level up to primary, 48.7% of which have an education level below primary or none (ORGC India 2001c). Education has been highlighted in several studies as an important barrier to the uptake of RETs (Bhide

& Monroy 2011, Jennings 2009, Kandpal & Broman 2014, Stigka *et al.* 2014). Jennings (2009) and Kandpal & Broman (2014) both outlined that education is vital for improving the level of awareness and uptake of renewables.

Respondents from households where the head of the household was responsible for deciding on the fuels used *($p<0.01$)* were less likely to be aware of the term renewable or sustainable energy. The survey results showed that the majority *(84.0%, $n=79$)* of households had a male as the head of the household. Where a male *($p<0.01$)* was responsible for deciding on the fuels used in the household, respondents were less likely to be aware of the term than households where a female was responsible. It can therefore be inferred that males are less aware of renewable and sustainable energy sources than females possibly because females are more involved in deciding on the fuels used and are more aware of the options that are available to them.

Respondents who choose their main fuel for household lighting because it was 'cheap' *($p<0.01$)* and 'easily available' *($p=0.01$)* were less likely to be aware of the term. This may be explained when you consider the individual fuels these households used. The majority of the respondents who gave 'easily available' *(72.2%, $n=52$)* and/or 'cheap' *(84.4%, $n=27$)* as reasons for using electricity as their main fuel for household lighting also indicated that they were 'happy' with this fuel. With a fuel that is easily available and cheap that they are happy using there are likely very few reasons for them to explore the alternatives that are available, which would reduce the likelihood of them being exposed to the term renewable or sustainable energy.

Respondents who used candles as an additional energy source for household lighting were significantly less likely *($p=0.04$)* to be aware of the term. Candles are a relatively common and easily available source of light and therefore reflects the lack of consideration a respondent gives when deciding the fuels they use as they select those that are easiest and most apparent. They are therefore unlikely to spend time and effort investigating alternatives which could explain why they have not come across this term.

Respondents were also less likely to be aware of the term if the main reason they used the fuel they did for household cooking was because it was cheap *($p<0.01$)*. 47.0% *($n=31$)* of these respondents were however unhappy with the primary fuel they used. It could be that their selection of fuels is constrained by their cost which is why they used a fuel that was cheap and affordable even if they were unhappy with it. Furthermore because their fuel selection is financially restricted they may not have the means to change fuels sources and so have not looked into the alternative options thus are unaware of what is available.

Respondents who made use of no other sources of energy for household cooking were significantly less likely to be aware of the term *($p<0.01$)*. This is most likely because the majority *(66.7%, $n=18$)* of these respondents were also happy with their primary fuel used for household cooking. As such they lacked the desire to find a better, more reliable fuel source.

The higher the monthly firewood/biomass consumption of a household the less likely *($p=0.01$)* a respondents was to be aware of the term. Firewood/biomass is a fuel that is often acquired at little or no cost. Households that consumed larger volumes of this fuel may do so because they could not afford to use any alternative modern sources that are available to them thus do not spend time exploring the option. It may also help explain why as the total household spend per month on firewood increased the likelihood of a respondent being aware of the term also decreased *($p=0.04$)*. These respondents are consuming a larger volume of firewood as they could not afford any alternatives thus do not explore the options available to them. Those whose monthly spend on firewood was low may reflect a low usage of this fuel as they can afford more efficient alternatives and may have encountered renewable or sustainable sources as options.

Respondents who had access to LPG *($p<0.01$)* or electricity *($p=0.01$)* for household cooking but did not use them were significantly less likely to be aware of the term. This is probably because these respondents could not afford to use these sources of energy as such they do not look past them for other alternative means of energy generation.

Respondents whose monthly fuel expenditure included electricity were less likely *($p=0.03$)* to be aware of the term. This is probably because the majority *(78.7%, $n= 37$)* of respondents who utilise electricity are happy with it and therefore have no reason to explore the availability of alternative energy sources.

Respondents whose household monthly expenditure included health care costs were significantly less likely *($p<0.01$)* to be aware of the term. This may be because the additional healthcare cost reduces their disposable income therefore restricting the flexibility they have in their choice of fuels and because of this they do not look into alternatives.

Respondents who would switch and pay slightly more for a renewable or sustainable energy supply if it meant helping protecting the local environment *($p=0.01$)*, and switch and pay slightly more for a renewable or sustainable energy supply if it meant a safer and more reliable supply *($p<0.01$)* were less likely to be aware of the term renewable or sustainable energy.

Respondents who would pay towards the set-up costs of renewable or sustainable energy supply if it meant a safer supply *($p=0.05$)* or a more reliable supply *($p=0.02$)* were less likely to be aware of the term.

The results of these four variables may at first seem paradoxical, however when it is considered that at this point in the surveying the respondent would have been provided with an overview of what the term renewable or sustainable energy meant it provides a startling insight. Respondents who before the study had not heard of renewable or sustainable energy were more likely to switch to or pay towards their set-up once given a definition of the term. However respondents who had heard of them before the study were less likely to switch or pay towards their set-up despite being given the same definition.

These finding suggests that an inaccurate understanding of renewable or sustainable energy provides more of a barrier towards their uptake than no knowledge of the term. These results are encouraging; it seems that people are willing to use RETs provided they understand them and their benefits. It also however indicates the damaging effect inaccurate education can have on peoples' decisions.

Respondents who were unhappy with the main fuel they used for household lighting were more likely *($p<0.01$)* to be aware of the term. This maybe a direct result of the dissatisfaction these respondents had in the fuel they were using, driving them to explore alternative energy resources that are available to them.

Respondents who had access to paraffin/kerosene for household lighting but chose not to use it were more likely *($p<0.01$)* to be aware of the term. This could be because these respondents were also more likely to have not used paraffin/kerosene because it was 'smoky' *($p=0.01$)*. It could be that the respondent's health and safety concerns about using this fuel source drove them to look for an alternative energy source which has made them aware of renewable and sustainable energy sources.

Respondents who used firewood/biomass *(p=0.02)* or paraffin/kerosene *(p=0.01)* as additional energy sources for household cooking were significantly more likely to be aware of the term. By selecting these fuels the respondents indicated that they had to make use of more than one energy resource for household cooking implying that they do not have access to a reliable energy source that can meet all of the energy requirements. Their awareness of renewable and sustainable energy may stem from exploring alternative energy sources that can better meet their energy needs.

An alternative reason may be that both of these fuel sources have been associated with a range adverse health and safety issues (Epstein *et al.* 2013, IEA 2007, Lam *et al.* 2012, Smith 2000, WHO 2009) and thus the respondents desire a safer energy source so have become aware of the term through examining alternative energy sources to switch to.

Respondents who made use of additional energy sources for cooking during rain were significantly more likely *(p=0.02)* to be aware of the term. These respondents probably experienced reliability issues with their primary fuel so have explored the alternatives options that are available to them.

Respondents who indicated that their use of other energy sources for household cooking was depended upon the fuels that were available were more likely *(p=0.03)* to be aware of the term. These respondents may have spent more time exploring and considering all the energy resource options that are available to them. Alternatively it could be that their access to certain fuel were restricted by factors such as their cost or physical availability and therefore have looked into alternative energy sources in order to access a more dependable supply.

Respondents who had access to paraffin/kerosene for cooking but chose not to use it because it is ‘expensive’ were significantly more likely *(p=0.03)* to be aware of the term. The majority of these respondents *(86.7%, n= 13)* used firewood/biomass as their primary fuel for household cooking. It may be that they desire to use a modern energy source and have spent time investigating those that are available as they cannot afford the conventional alternatives that are currently available.

Respondents that had access to firewood/biomass for household cooking but chose not to use it were significantly more likely *(p=0.03)* to be aware of the term. These respondents could already be using a higher level of energy resource (e.g. LPG, electricity) so may be aware of renewable or sustainable energy sources as they are alternative sources of modern energy. These respondents may alternatively not have used firewood/biomass because of the health and safety concerns and are aware of the term because these factors have driven them to look for better alternatives.

Respondents who had more advanced appliances such as kettles *($p<0.01$)* or telephones *($p=0.01$)* were more likely to be aware of the term. An explanation for this is that these respondents are more aware of modern energy sources as they are using appliances that utilise them. Those that continue to use appliances that utilise more traditional fuels, either by choice or circumstance, are less aware of the term as they have no reason to consider alternatives.

Respondents from households that had additional sources of income beyond paid employment were more likely *($p=0.01$)* to be aware of the term. The households were also more likely to have a higher total household income. It could therefore be assumed that the higher income allows these household to be more selective with the fuels they used so they have explored more of the options available to them. Rao & Reddy (2007) found that higher income households had a greater choice when it came to selecting household fuels, and tended to opt for cleaner more efficient fuels (Rao & Reddy 2007).

6.2.2. Factors Affecting Attitudes Towards The Provision Of Renewable Or Sustainable Energy Sources.

Outcome Variable 2: Do you think communities like your own should be provided with these types of alternative [renewable or sustainable] energy supplies?

The results of the binomial logistic regression using outcome variable 2 are presented in Appendix 1, Section A.1.2.

Respondents who used ‘bamboo’ as the main material for household roofing were significantly less likely *($p=0.02$)* to believe that communities such as their own should be provided with renewable or sustainable energy supplies. Bamboo is a cheap material to use for construction and may reflect the respondent economic status. The mean total household income of respondents who used bamboo for roofing was 38.7% less than those who did not. There lower income may mean a smaller disposable income, therefore may have concerns about how affordable these energy supplies will be.

Respondents whose main reason for using the primary fuel they used for household cooking was because they ‘cannot afford other fuels’ were less likely *($p=0.02$)* to think that renewable or sustainable energy supplies should be provided to communities such as their own. As seen with the respondents who used bamboo for roofing, these respondents may not have as much financial flexibility so see no benefit in being given access to an energy source they cannot utilise.

Respondents who used their main fuel for cooking because it was a 'familiar fuel' were significantly more likely *(p=0.04)* to think renewable or sustainable energy sources should be provided. These respondents may not wish to take risks with the fuels they use hence why they stick with one they are accustomed to. This however does not mean they do not want change, in fact 40.0% *(n=23)* of these respondents were unhappy with their main cooking fuel, but rather the alternatives available to them are not appealing enough to encourage them to change.

Respondents who identified solar panels *(p=0.02)* as an example of a renewable or sustainable energy source, or indicated having heard of hydroelectricity *(p=0.05)* or solar panels *(p<0.01)* were more likely to think that communities such as their own should be provided with these types of alternative energy sources. This is unsurprising as it is likely their prior knowledge has given them a more informed view of the benefits offered and therefore makes them more inclined to support the implementation of these types of energy provision.

Unsurprisingly respondents were significantly more likely to believe that communities such as their own should be provided with these types of alternative energy sources if they identified biogas *(p=0.01)* or solar panels *(p<0.01)* as energy sources they believed would beneficial to communities such as their own. Similarly those who indicated that they did not think any of these energy sources would provide a benefit were less likely *(p=0.04)* to believe that communities such as their own should be provided with them.

It makes sense that the way these respondents feel about the benefit that these energy sources can offer would affect their attitude towards their expanded use.

Respondents who thought that renewable or sustainable energy sources should be used over current means of energy provision were also significantly more likely *(p<0.01)* to think these energy sources should be provided to communities such as their own. This relationship make sense as it is understandable that those respondents who think they should be provided with these energy supplies also think they should be used over their current energy supplies. The association between these two variables is a good indication that not only is there acceptance towards the use of renewable or sustainable energy sources but also a desire for their use too.

Respondents that were willing to switch to a renewable or sustainable energy source if it was the same price but also meant helping protect the local environment were significantly more likely *($p=0.02$)* to believe that communities such as their own should be provided with these types of alternative energy supplies. These respondents may be environmentally conscious and it is this factor that drives their acceptance of and belief that renewable or sustainable energy sources should be provided to communities such as the own.

However when cost is introduced as a factor a change is seen. Respondents who indicated that they would switch and pay slightly more for renewable or sustainable energy source if it meant helping protect the local environment were significantly more likely *($p=0.04$)* to believe that communities such as their own should be provided with these types of alternative energy supplies. The total number of respondents however to indicate this is noticeably fewer than the total number of respondent who would previously switch for the same benefit but if cost stayed the same. This would imply that fewer respondents are as environmental conscious as first thought and it is unlikely to be their primary reason for believing that renewable or sustainable energy sources should be provided to communities similar to their own.

Respondents that would switch to a renewable or sustainable energy source if it was the same price but meant a safer more reliable supply were significantly more likely *($p<0.01$)* to believe that communities such as their own should be provided with these types of alternative energy supplies. These respondents are probably already looking for a fuel that is safer and/or more reliable than that which they are currently using. Therefore the provision of any alternative energy sources is seen as a potential improvement.

Respondents who were willing to switch to a renewable or sustainable energy source even if it meant paying slightly more but meant a safer more reliable supply were significantly more likely *($p=0.03$)* to believe that communities such as their own should be provided with these types of alternative energy supplies. As seen previously the cost associated with using a renewable or sustainable energy source has an important impact on a respondents' attitude toward them. Far fewer respondents were willing to pay slightly more for the same benefits. This could therefore mean that safety and reliability are not important characteristics to all respondents who may have alternative motivation for believing that these energy sources should be provided to communities such as their own.

6.2.3. Factors Affecting Attitudes Towards The Use Of Renewable Or Sustainable Energy Sources.

Outcome Variable 3: Do you think these types of energy [renewable/sustainable] should be used over current means of energy provision?

The results of the binomial logistic regression using outcome variable 3 are presented in Appendix 1, Section A.1.3.

Respondents who were unhappy with the main fuel used for household lighting because they considered it to be ‘unreliable’ were significantly less likely *(p=0.01)* to believe that renewable or sustainable energy sources should be used over current means of energy provision. This may be explained by the fact that these respondents were also significantly more likely *(p=0.03)* to have used their main fuel for lighting because it was a ‘familiar fuel’. It may be that despite being unhappy with their fuel they do not wish to use an energy source that they know nothing about and therefore would not support their widespread introduction.

Respondents who were unhappy with their primary fuel for household cooking because it was ‘smoky’ were significantly less likely *(p=0.01)* to believe that these energy sources should be used over current means of energy generation. The reason for this may be because this variable was also significantly associated with the variables ‘Reasons for using main fuel for household cooking’; ‘cannot afford other fuels’ *(p<0.01)* and ‘cheap’ *(p<0.01)*. With respondents who indicated ‘smoky’ more likely to give these as their reasons for using their primary fuel for cooking. Furthermore the variable ‘Total household income per month’ was also found to be significantly associated *(p=0.02)*, the smaller the total income the more likely the respondent were to be unhappy because their main fuel was ‘smoky’.

It is plausible then to assume that these respondents may be unable to afford the alternatives energy sources that are already available to them due to a lack of income and therefore do not see a benefit in using these energy sources over current means of energy generation as they would not be able to afford to use them.

Respondents who believed that renewable or sustainable energy sources ‘would be no benefit’ were significantly less likely *(p<0.01)* to think that these types of energy sources should be used over current means of energy provision. This association makes sense as if they did not think they would provide any benefit they would not have any reason to support their use over current means of energy generation. It could be suggested that their belief that these types of energy sources [renewable or sustainable] would not offer any benefits could be the result of a lack of knowledge or understanding of these energy sources, or worse a lack of factual information.

Respondents from households that used concrete as the either their main material for roofing *($p=0.01$)* or flooring *($p=0.03$)* were significantly more likely to believe that these energy sources should be used over their current means of energy provision. Households that used concrete as a building material were found to have a significantly higher number of rooms in the household. In Chapter 4 larger households were found to be associated with larger number of people in the household. This may mean that there is a higher demand for energy that current means of provision cannot satisfy and therefore the respondents support a move to use alternative sources in the hope that it will be able to meet their demand.

Respondents who chose to use the main fuel they did for household lighting because it was ‘cheap’ were significantly more likely *($p<0.01$)* to think that these energy sources should be used over current means of provision. An explanation for this may be that households with a higher total monthly expenditure on fuel were found to be significantly more likely *($p=0.01$)* to choose their main fuel for lighting because it was ‘cheap’. These household may have to use the cheapest fuel available in order to meet their energy demand but do desire an affordable alternative modern energy source.

The longer a household spends cooking over a 24 hour period the significantly more likely *($p<0.01$)* they were to believe that these energy sources should be used over current means of energy provision. Having to spend a longer period of time cooking might indicate two things, firstly it may be that there are more people in the household which could also mean a higher energy demand, or secondly that they are having to spend more time cooking because the fuels they are using are inefficient. Both of these issues could be the reason why these respondents supported the use of alternative energy sources over their current means as they desire a fuel that is more efficient and can meet their energy demands.

These reasons may also explain why household whose monthly expenditure included ‘clothes’ *($p<0.01$)* or ‘healthcare’ *($p<0.01$)* were significantly more likely to think these energy sources should be used over current means of generation. Both of these variables are significantly associated to the variable ‘times spent cooking per 24 hours’ *($p<0.01$)*. It is possibly the effect of this association which are being observed, with respondents supporting the use of renewable or sustainable energy sources as their current sources may be unable to fully meet their current demand.

Respondents who were happy with the main fuel they used for cooking were significantly more likely *($p=0.05$)* to believe that renewable or sustainable energy sources should be used over their current energy supplies. These respondents were also significantly more likely *($p<0.01$)* to use LPG as their main fuel for cooking, and to indicate the reason for using their main fuel was because it was 'easy to use' *($p<0.01$)*. It may be this previous experience of using a modern energy source that was 'easy to use' that makes them believe that renewable or sustainable energy sources should be used over current means of energy provision.

Respondents from households whose monthly expenditure included electricity were significantly more likely *($p=0.04$)* to believe that renewable or sustainable energy sources should be used over current means of energy provision. A possible explanation for this is that the experience respondents have had with a modern energy source has made them favour their use which is why they believed renewable or sustainable sources should be used over current means.

A respondent was more likely to think that these energy sources should be used over current means of energy provision if they indicated that they had heard of 'solar panels' *($p<0.01$)*. These respondents have some awareness of these energy sources so may also have a better understanding of the benefits they can offer which is why they were more inclined to support their use over current means of energy provision.

For similar reasons respondents who indicated that they believed 'biogas' and/or 'solar power' would be a beneficial energy supply were significantly more likely *($p<0.01$)* to think that renewable or sustainable energy sources should be used over current means of energy generation. It is reasonable to suppose that their prior awareness of these energy sources makes them more inclined to favour their use over current methods of energy provision.

Respondents, unsurprisingly, were significantly more likely *($p<0.01$)* to think that renewable or sustainable energy sources should be used over current means of energy provision if they also thought that communities like their own should be provided with these types of alternative [renewable or sustainable] energy supplies.

The variable ‘would you switch if same price for energy from renewable or sustainable source if: you knew it was helping protect local environment?’ was significantly associated *($p=0.02$)* with the outcome variable with respondents who indicated ‘yes’ being more likely to support the idea of using these energy sources over current means of energy provision. This association could highlight an awareness of the environmental benefits these types of energy resource can offer which could be the reason they believed that they should be used over their current means of energy provision.

However as previously seen the cost associated with using a renewable or sustainable energy source has an impact on a respondents’ attitude towards them. Respondents who would pay slightly more for energy from a renewable or sustainable energy source if it meant helping protect the local environment were still more likely *($p<0.01$)* to think that these energy sources should be used over current means of energy generation, however fewer respondents were willing to pay the increase in order to gain these benefit. Therefore it is reasonable to assume that although the respondents still consider the environmental benefits a reason to use these alternative energy sources over current means, the cost is a more important factor which could prevent their uptake.

The variable ‘would you switch if same price for energy from renewable or sustainable source if: you knew it was a safer and more reliable supply?’ *($p=0.02$)* and ‘would you switch and pay slightly more for energy from renewable or sustainable sources if: you knew it was safer and more reliable?’ *($p<0.01$)* are both significantly associated with the outcome variable with respondents who said ‘yes’ being more likely to believe that renewable or sustainable energy sources should be used over current means of energy generation. This could indicate that the respondent believe that these energy sources should be used in order to provide a safer and more reliable energy supply than that which is currently being utilised. However cost is again seen as an important factor, with far fewer respondents being willing to pay more for the same benefits. This again points toward cost being a barrier towards uptake.

Respondents who were willing to pay towards the set-up costs of a renewable or sustainable energy supply if it meant a cheaper supply were significantly more likely *($p<0.01$)* to think that renewable or sustainable energy sources should be used over current means of energy provision. As shown in the previous variables cost appears to be the underlying factor which influences these respondents. There is obviously a desire to pay less for household energy, even so that they are willing to pay in order to have access to one. This implies that the respondents are also considering the long term benefits over the short term costs and may be what drives the respondents to support the use of renewable or sustainable energy supplies over current means.

Respondents who were willing to pay towards the set-up costs of a renewable or sustainable energy supply if it meant a more reliable supply were significantly more likely *($p<0.01$)* to think that renewable or sustainable energy sources should be used over current means of energy provision. These respondents must believe that using renewable or sustainable energy sources over current means of energy provision will provide them with a more reliable energy supply, which is why they support their use. Reliability must be a characteristic desired by these respondents which is why they were willing to pay to have access to a fuel that offers it.

6.2.4. Factors Affecting Willingness To Contribute Towards The Set-Up Of Renewable Or Sustainable Energy Sources

Outcome Variable 4: Would you pay part of set-up costs for a renewable or sustainable energy supply if it meant: cheaper supply?

The results of the binomial logistic regression using outcome variable 4 are presented in Appendix 1, Section A.1.4.

Respondents from households that used firewood/biomass as their main energy source for household lighting were significantly less likely *($p=0.01$)* to pay towards the set-up than those who used electricity as their main source energy for household lighting. A plausible explanation for this is that those respondents who used electricity probably have a higher expenditure on fuels used in the household. Therefore their readiness to pay towards the set-up is purely motivated by wanting to reduce the cost of their energy consumption in the long term.

Respondents who were unhappy with their main fuel for lighting because it was ‘unreliable’ were significantly more likely *($p<0.01$)* to say ‘no’ to contributing towards the set-up costs even if it meant a cheaper energy supply. This association may be the result of a lack of knowledge and understanding surrounding renewable or sustainable energy sources as is suggested by these respondents also being significantly more likely *($p<0.01$)* to say that they did not think these types of energy sources would offer any benefit to communities such as their own. It is reasonable to assume that this is the reason why these respondents would not contribute towards their set-up as they may not consider them to be any better than the energy sources they are already using.

Households that had access to but did not use electricity for household cooking because it was not easily available were less likely *(p=0.03)* to say ‘yes’ to contributing towards the set-up costs. An explanation for this may be that these respondents have had little or no experience of using a modern energy source so they are unaware of the benefits they can offer. Therefore they do not have sufficient reason to contribute towards the set-up of one even if it means a cheaper supply.

Respondents who lived in larger houses, as indicated by having a higher number of rooms *(p=0.05)* or windows *(p=0.03)*, were significantly more likely to pay towards the set-up costs for a cheaper supply. These households probably have a higher energy demand which result in higher fuel expenditure. This is supported by the fact that the variable ‘number of rooms in the household’ had a significant *(p<0.01)* positive correlation with the variable ‘total household monthly fuel expense’. It is therefore plausible that the reason these respondents would pay towards the set-up is that in the long term they believe it will benefit them financially as they will be able to reduce their overall energy expenditure.

Respondents from household where the head of the household was responsible for deciding the fuels used were significantly more likely *(p=0.02)* to pay towards the set-up. The head of the household is most likely the person who makes most if not all of the financial decisions in the household. Therefore the prospect of being able to save money in the long term, which will give them more flexibility in the household budget, is a plausible reason for considering to contribute towards set-up costs.

Households where additional energy sources for lighting was used ‘during power cuts’ were significantly more likely *(p=0.01)* to indicate that they would contribute towards the set-up. Having to make use of multiple different energy resources may result in higher expenditure especially if the power cuts cause prices to increases as the demand for alternatives increases. Access to a cheaper energy source may enable these households to be better prepared to deal with price shocks that may also occur during power outages. Alternatively these respondents may be willing to pay towards the set-up as they hope they may offer a more reliable energy supply.

Respondents whose household used firewood/biomass as an additional fuel source for cooking were significantly more likely *(p=0.01)* to pay towards the set-up costs. As previously suggested households that have to use multiple energy resource may not have access to a reliable energy source that can meet all of their energy requirements which may result in higher fuel expenditure. In addition the cost of using their primary fuel may mean they cannot afford to use it all of the time. These respondents were also previously shown to be more aware of the term renewable or sustainable energy. It is likely that being aware of the benefits these energy sources can offer and the incentive to have access to a cheaper energy source are the reasons these respondent would contribute towards their set-up.

Household that used electrical lights for lighting were more likely *($p=0.02$)* to pay towards the set-up. Furthermore the more electrical lights used the more likely *($p=0.02$)* they were to contribute. Both of these variables were found to be significantly associated with the variable 'are you happy with the main fuel used for household lighting?' *($p=0.01$, $p<0.01$, respectively)*. As these respondents had already been using a modern energy source in the form of electricity that they were happy with, it is logical that they would want to continue using a modern energy resources and if they could do so at a reduced cost it would be an additional benefit. It is for these reasons these respondents were more likely to pay towards the set-up costs.

Households that used equipment powered by electricity to cool the house were significantly more likely *($p=0.01$)* to say 'yes' to paying towards the set-up costs if it meant a cheaper supply. As previously highlighted respondents with previous experience of using modern energy sources are more inclined to contribute towards their set-up because they are already aware of many of the benefits these energy sources offer. Furthermore these respondents may be considering that if the cost of using this energy source is cheaper they would be able to expand their use of it into different household activities, or alternatively the saving they make could be used to improve other aspects of their life.

Respondents that used a higher volume of paraffin/kerosene per month were more likely *($p=0.03$)* to contribute towards the set-up costs. These respondents are most likely financially motivated, they are willing to contribute as they hope in the long term they will be better off.

Unsurprisingly households with higher total monthly fuel expenditure were significantly more likely *($p=0.02$)* to pay towards the set-up. The reason for this association is clearly that these respondents want to reduce their fuel expenditure. This in turn would provide them with more of a disposable income to be used in other areas.

Household were significantly more likely to pay towards the set-up of a renewable or sustainable energy supply if it meant a cheaper supply if their monthly expenditure included ‘clothes’ *($p<0.01$)* and/or ‘health care’ *($p=0.01$)*. As previously discussed these two variables are also significantly associated with the variable *‘times spent cooking per 24 hours’ ($p<0.01$),* and as previously highlighted this relationship could indicate a higher energy demand. These respondents may therefore be more inclined to pay to set-up a supply that is ultimately cheaper in order to reduce their total fuel expenditure and provide them with more flexibility in their household budget.

The same rationalisation could be given for the variable ‘total household monthly expenditure (excluding fuel)’. Households with a higher monthly expenditure were more likely *($p=0.03$)* to pay towards the set-up if it meant a cheaper supply. The reason ultimately being a reduction in the households’ monthly fuel expenditure, which in turn potentially means an increase in the household’s disposable income.

Respondents who have heard of ‘solar panels’ as an example of a renewable or sustainable energy were significantly more likely *($p=0.01$)* to pay towards the set-up. These respondents may already have an understanding of the benefits that using these technologies can offer which may be the reason they are willing to contribute towards their set-up, with the cheaper supply simply being an added bonus. However it is far more likely that the reduced energy costs are the real driver and that any other benefits gained from the technology are merely the secondary benefits of their use.

Respondents who believed ‘solar power’ would be a beneficial energy source were more likely *($p=0.01$)* to say ‘yes’ to paying towards the set-up of a renewable or sustainable energy supply. Those who believed that renewable or sustainable energy sources would not offer any benefit were more likely *($p=0.02$)* to say ‘no’. These associations make sense as why would a respondent pay towards an energy source that they did not think offered any benefit? Whereas those who did believed they would be of benefit, in this instance a cheaper supply, were willing to pay in order to access these perceived benefits.

Respondents who thought that renewable or sustainable energy sources should be used over current means of energy generation were significantly more likely *($p<0.01$)* to contribute towards the set-up costs. As previously discussed a possible explanation for this association may be that there is already a desire to have access to cheaper forms of energy. So when the opportunity arises to secure access in the form of an energy resource the respondents already think should be used over their current means of energy provision they have double the incentive to contribute towards their set-up.

Respondents were also more likely to pay towards the set-up costs of a renewable or sustainable energy source if they were willing to switch and pay the same *($p=0.04$)*, or switch and pay slightly more *($p<0.01$)* for a renewable or sustainable energy supply but knew it was helping protect the local environment or switch and pay slightly more if they knew it meant a safer and more reliable supply *($p<0.01$).*

An explanation for these associations is that these respondents are not in fact switching for the benefits but instead desire to have access to a form of modern energy. The costs of the energy source is however a limiting factor which is why the number of respondents drops between paying the same and paying slightly more for an energy source that helps protects the local environment. It also helps explain why far more respondents were willing to pay towards the set-up if it ultimately means a cheaper supply as they are considering the long term benefits over a one off payment.

Outcome Variable 5: Would you pay part of set-up costs for a renewable or sustainable energy supply if it meant: safer supply?

The results of the binomial logistic regression using outcome variable 5 are presented in Appendix 1, Section A.1.5.

Respondents from households that used straw/thatch *($p<0.01$)* as their main material for household roofing, or mud *($p=0.01$)* as their main material for flooring were significantly less likely to pay towards the set-up of a renewable or sustainable energy source. Use of these material may indicate a poorer household. Safety may well be a characteristic they desired, but on its own may be an insufficient incentive to encourage these respondents to use what little income they have to contribute. It may be that they do not have the flexibility in their household budget to be able afford to contribute even if they desired a safer energy source.

Respondents that had access to paraffin/kerosene for household lighting but chose not to use it were significantly less likely *($p=0.04$)* to pay towards the set-up costs. It may be that these respondents did not use paraffin/kerosene because they could not afford to. Therefore it is reasonable to assume that they would not be able to afford to contribute towards the set-up costs even if they desired a safer energy source, because they did not have the financial capability to do so.

The effect income has on investing in these projects is highlighted by the fact that respondents who used their main fuel for cooking because they could not afford other fuels were less likely *($p<0.01$)* to say 'yes' to contributing towards the set-up. It is reasonable to assume that as these respondents do not have the flexibility in their households income, which restricts their choice of fuel used, they would be unable to afford to contribute even if they desired a safer energy source.

Households where the respondents reason using alternative energy sources for household cooking was when it was raining were less likely *($p=0.01$)* to pay towards the set-up. Despite the problems that these respondents experienced with their primary fuel it is clear that safety is not of paramount concern or it may have been more of an incentive to encourage respondents to contribute.

Respondents who had access to paraffin/kerosene for cooking but chose not to use it were significantly less likely *($p<0.01$)* to pay towards the set-up costs even if it offered a safer supply. These respondents may not be using the source of paraffin/kerosene that is available to them as they could not afford to or because they did not consider it a safer energy supply. It is therefore possible that the reason they are less willing to contribute is because they cannot afford to do so. However it is more likely that the fuels they used they considered to be safe therefore 'safety' as a characteristic alone is an insufficient incentive to sway these respondents to pay towards set-up costs.

Households where the respondents indicated having access to candles for household cooking but chose not to use them were significantly less likely *($p=0.04$)* to pay towards the set-up costs of a renewable or sustainable energy source. These respondents may simply be unable to afford to contribute, even if they did desire a safer energy supply as they do not have the income or flexibility in their household budgets to be able to contribute.

Respondents who did not have access to any other energy sources for household cooking other than that which they used as their primary or additional fuel were less likely *($p<0.01$)* to pay towards the set-up costs even if it meant a safer supply. The reason for this association may be because these respondents were also significantly more likely *($p=0.04$)* to say the reason they used the main fuel for cooking was because they 'cannot afford other fuels', so when they talk about fuels not being accessible it is reasonable to assume that they mean they are unaffordable. This would explain why they are less likely to contribute towards set-up costs because they are not in a position to do so.

Respondents whose monthly household fuel expenditure included ‘firewood/biomass’ were less likely *($p=0.01$)* to contribute towards the set-up costs. Interestingly these households were more likely *($p<0.01$)* to have a lower total household income which could explain why they were less inclined to contribute. It may be that they just cannot afford to even if they desired a safer fuel, which is likely as they were also more likely to cite ‘health concerns’ *($p<0.01$)* as a reason for being unhappy with their main fuel for cooking.

Respondents who were aware of the term renewable or sustainable energy before this study were less likely *($p=0.05$)* to pay towards the set-up costs. It is possible that safety simply is not as important a characteristic to these respondents, so alone is insufficient to encourage them to contribute. Alternatively it may be that these respondents have an inaccurate understanding of renewable or sustainable energy sources which has led them to see no advantage in their use regardless of the benefit of a safer supply.

Respondents from the village Shishupal Garh were significantly more likely *($p=0.02$)* to pay towards the set-up costs if it meant a safer supply. These respondents may not have what they consider to be a safe supply of energy which would therefore warrant their willingness to pay for a safer supply.

Respondents from larger households, as indicated by a higher number of rooms *($p=0.01$)* and windows *($p<0.01$)*, as well as the number of levels the household was spread over *($p<0.01$)* were significantly more likely to pay towards the set-up costs. Larger households tended to have a significantly higher income from employment *($p<0.01$)*. It is likely that safety is a characteristic these respondents desire in their fuels which is why they were willing to pay towards the set-up. It may not be that respondents from smaller household do not desire a safer energy source just that they did not have a sufficient income which would allow them to contribute.

The effects of a larger household may also explain why respondent from households that used concrete for roofing were more likely *($p<0.01$)* to contribute towards the set-up of a renewable or sustainable energy source. The use of concrete as a material for roofing was shown previously to be associated with larger households. So what might be being observed is the association between household size and the outcome variable.

Where the head of the household was responsible for deciding the fuels used respondents were more likely *($p<0.01$)* to contribute towards the set-up costs. The results showed that the majority *(84.0%, $n=79$)* of the heads of the households were male. The results also show that when a male was in charge of selecting the fuels used they were more likely *($p<0.01$)* to contribute than when a female is in charge. It is reasonable to assume that we are observing the same association in these variables to the outcome variable with the influencing factor being gender. What can be drawn from this is that males consider safety to be an important characteristic in the fuels used in the household.

Respondents were significantly more likely to say 'yes' to contributing towards the set-up costs of an energy source if they indicted using the main fuel they used for household lighting because it was 'cheap' *($p<0.01$)* or 'easily available' *($p=0.03$)*.

The respondents who indicated 'cheap' may have little flexibility in their household budgets therefore are restricted to using certain fuels. However their willingness to pay toward the set-up costs may be because they are considering the long term benefits as they will ultimately have a safer energy supply. The respondents who indicated 'easily available', the incentive of a safer fuel may be sufficient enough for them to contribute.

Households where the respondents were happy with the main fuel they used for lighting were more likely *($p<0.01$)* to pay towards the set-up costs. For this association it is reasonable to assume that the incentive of a safer energy supply is what motivates these respondents to contribute. Again these respondents are probably considering the long term benefits over the short term costs.

Where respondents gave the reason they made use of an alternative energy resource because of power cuts they were also significantly more likely *($p<0.04$)* to say 'yes' to paying towards the set-up if it meant a safer supply. This association may be being observed for two reasons. Firstly it may be that these respondents simple require an alternative energy supply that is more reliable and are therefore willing to contribute in the hope these technologies will offer this. Secondly it may be that the power cuts pose a safety issue as the respondents may be having to use fuels such as firewood/biomass or paraffin/kerosene that are not considered safe. Therefore these respondents may be willing to contribute to avoid having to use these alternatives.

Respondents that used electrical lights for household lighting were more likely *($p<0.01$)* to pay towards the set-up of renewable or sustainable energy supply. Furthermore the more electrical lights respondents used the more likely *($p<0.01$)* they were to also say 'yes' to contributing. It is likely that these respondents despite using electricity do not consider the method of it delivery to be safe. This would explain why they were willing to contribute as they not only desired the energy being provided but a safer means of its delivery.

This explanation could also explain why households that used fans/air conditioning to cool the house for a longer period in the summer were significantly more likely *($p<0.01$)* to pay towards the set-up of a renewable or sustainable energy supply. The vast majority of these respondents *(90.4%, $n=85$)* used electricity to power the equipment used to cool the household, those that used electricity were also more likely *($p=0.02$)* to pay towards the set-up cost. The association we are seeing in these two variables to the outcome variable is linked to the use of electricity. It is therefore plausible that these respondent are willing to contribute in order to maintain making use of the energy services derived from electricity but through a resource that offers a safer method of delivery.

The higher the volume of fuel used in fuel lamps over a 24 hour period the more likely *($p=0.03$)* a respondent was to contribute towards the set-up. These lamps used paraffin/kerosene. The respondents may be aware of the hazards and negative health implications that are associated with using paraffin/kerosene (poisoning, explosions, fire, increased risk of respiratory problems, low birth weight, increased risk of cancer (Epstein *et al.* 2013, Lam *et al.* 2012, WHO 2009)) which would explain why they were willing to pay towards the set-up of an energy source that was safer as those using higher volumes are potential at a greater risk.

The longer the period of time that is spent cooking in a household per 24 hours the more likely *($p<0.01$)* a respondent was to pay towards the set-up if it meant a safer supply. As previously highlighted spending a longer period of time cooking may imply the use of an inefficient fuel, this may mean increased exposure to indoor air pollutants, and it may be this that motivates respondents to contribute.

Respondents who used LPG as their main fuel for household cooking were more likely *($p<0.01$)* to pay towards the set-up costs, than respondents who used firewood/biomass. The respondents who used LPG may not consider this fuel to be a safe source of energy however they do prefer this type of modern energy resource. This would explain their willingness to pay towards the set-up costs. The respondents who used firewood/biomass may have been less inclined to pay towards the set-up costs because they were also significantly more likely *($p<0.01$)* to have a lower monthly household income, therefore may have insufficient income to be able to contribute, however it may be that ‘safety’ alone is an insufficient incentive to convince these respondents to invest.

Respondents who were happy with their main fuel for cooking were significantly more likely *($p<0.01$)* to pay towards the set-up. Further investigation found that respondents whose main fuel was LPG were more likely *($p<0.01$)* to be happy with their main fuel than those who used firewood/biomass. As previously discussed respondents who used LPG may not consider this fuel to be a safe source of energy but do like this type of modern energy provision, which is why they would contribute towards the set-up.

Respondents from households where the reason they were unhappy with their main fuel for cooking was because it was ‘smoky’ were significantly more likely *($p<0.01$)* to say ‘no’ to paying towards the set-up costs. This was an odd result as it would be expected that these respondents would want a safer energy source to avoid the adverse impacts of using a smoky fuel. However, as previously discussed this variable was also associated with the variables: reasons for using main fuel for household cooking: ‘cannot afford other fuels’ *($p<0.01$)* and ‘cheap’ *($p<0.01$)* as well as ‘Total household income per month’ *($p=0.02$)*. These associations help provide an explanation for this association with the outcome variable. It likely that these respondents would not contribute towards the set-up costs simply because they are in a situation where they cannot afford to do so.

Respondents who made use of alternative energy source for cooking when their primary fuel was unavailable were more likely *($p=0.02$)* to pay towards the set-up costs. These respondents were significantly more likely to use firewood/biomass *($p<0.01$)* or paraffin/kerosene *($p<0.01$)* as their alternative fuel for cooking. Both of these fuels are associated with various negative health and safety concerns, it is therefore plausible that these respondent were willing to contribute in order to access a safer energy source which could be used instead.

This association however contradicts previous findings which suggested that those whose monthly fuel expenditure included firewood/biomass were less likely to contribute. It may be that the respondents who had to pay for the firewood/biomass they used did not use it as frequently and therefore do not consider the potential health implications to be of major concern.

Household that used paraffin/kerosene as either their primary or alternative energy source for household cooking were more likely *(p=0.01)* to pay towards the set-up costs if it also meant a safer supply. Furthermore the more paraffin/kerosene fuel used per month the more likely *(p=0.05)* respondents were to contributing. As highlighted for the associations of other variables the hazards associated with the use of paraffin/kerosene have been well documented (Epstein *et al.* 2013, Lam *et al.* 2012, WHO 2009). It is therefore sensible to conclude that it is these negative's that motivate respondents to pay towards the set-up as ultimately they desire access to a safer form of energy.

Households that used LPG as either primary or alternative energy source were also more likely *(p<0.01)* to pay towards the set-up. It is likely that we are observing this association with the outcome variable for the same reason we saw the association between the outcome variable and respondents who used LPG as their main fuel for household cooking. These respondents enjoy the modern energy services that are provided by using LPG but do not consider the fuel to be a safe source. Therefore they are willing to contribute in order to continue receiving these services while satisfying their desire for a safer energy source.

Respondents were significantly more likely to pay towards the set-up costs if their household monthly expenditure included LPG *(p=0.01)*, paraffin/kerosene *(p<0.01)* or electricity *(p<0.01)*. As previously highlighted all of these fuels may be considered unsafe by their users which would explain their readiness to pay towards the set-up costs for a safer supply.

The higher a households total monthly fuel expenditure the more likely *(p=0.01)* they were to contribute towards the set-up of a renewable or sustainable energy supply. This association is probably a result of the positive correlations this variables has with total monthly household expenditure on 'electricity' *(p<0.01)*, 'LPG' *(p=0.01)* and 'paraffin/kerosene' *(p=0.03)*. The association with the outcome variable is therefore most likely a reflection of the concerns regarding safety these respondents have with their individual fuels.

Respondents from households that bought all the fuels they used were significantly more likely *(p=0.01)* to contribute towards the set-up of a renewable or sustainable energy source. This is likely more to do with the people that did not buy all their fuels. It is reasonable to assume that if they could not afford to buy all their fuels it is unlikely they will be able to afford to contribute towards the set-up even if they desired a safer supply.

Households with a higher total weekly income from employment *(p=0.03)* and a higher total monthly income from all sources *(p=0.01)* were significantly more likely to pay towards the set-up of a safer supply. Household that had additional sources of income beyond employment were also significantly more likely *(p=0.05)* to pay towards the set-up. Furthermore the higher the male weekly income from employment the more likely *(p=0.05)* respondents were to pay towards the set-up. Male income accounts for the majority of a households total income from employment it is therefore likely to be the more relevant underlying factor.

Regardless, the higher the household's income the more flexibility they may have in the household budget to be able to reallocate funds to cover the set-up costs. This would however also require the respondents to have a prior desire for a safer form of energy otherwise there would be no reasons for them to want to do this. This desire probably can be found through the significant *(p=0.04)* positive association between household with a higher weekly income from employment and the variable 'total household fuel expenditure per month'. The significance of this variable to the outcome variable has been discussed previously with safety concerns surrounding the fuels used being the likely factor driving the desire for a safer energy source.

Household were more likely to pay towards the set-up costs if their monthly expenditure included transport *(p=0.01)*, clothes *(p<0.01)* and/or health care *(p<0.01)*. It is likely that there is some underlying factor that makes these respondents already predisposed towards wanting a safer source of energy provision which is why they were willing to contribute. It could be that because the mean household expenditure on healthcare was 11.69 GBP per month these respondents hope that by investing in a safer fuel they will be able to reduce their healthcare costs in the long term by using a safer fuel source.

Respondents were also more likely to say 'yes' to paying towards the set-up costs the higher their total monthly expenditure *(p<0.01)* was excluding fuels. In particular the higher a households monthly expenditure on food *(p<0.01)*, transport *(p=0.05)*, and/or education *(p=0.02)* the more likely they were to contribute. It is reasonable to assume that having higher outgoing would mean also having a higher total income it may therefore be a factor linked to this variable which explains the true reason these respondents would contribute towards set-up costs.

Respondents who had heard of ‘solar panels’ as a means of renewable or sustainable energy provision were more likely *($p<0.01$)* to contribute towards the set-up costs. Those who identified ‘solar power’ as a beneficial energy source were also more likely *($p<0.01$)* to contribute. What could be being observed here is because of the belief these respondents have in solar power, therefore solar panels, to be a beneficial energy source they are willing to pay towards their set-up. The safety aspect may not be a factor it could be they are happy to invest simply to gain access to this energy resource.

Respondents who had a preferred renewable or sustainable energy source were more likely *($p=0.01$)* to pay towards the set-up of one of these energy sources if it also meant a safer supply. Of these, the respondents who indicated that they preferred solar energy over biogas were significantly more likely *($p=0.02$)* to contribute.

These associations with the outcome variable may be the result of the respondents’ preference towards solar power. As seen in the previous variables respondents who identified solar power as a beneficial source of energy were more likely to contribute towards the set-up costs. It is likely that it is actually this preference that motivates the respondents rather than the desire for a safer energy supply, and explains why these two variables are also significantly associated with the outcome variable.

Respondents who indicated that they would switch and pay slightly more for energy from renewable or sustainable energy sources if they knew it was helping protect the local environment were more likely *($p<0.01$)* to contribute towards the set-up costs. An explanation for this could be that these respondents are financially able and willing to pay more or contribute in order to be able to access a source of modern energy. The benefits of a safer supply or a supply that helps protect the environment may not be central to their decision.

Respondents who said that they would switch and pay slightly more for energy from renewable or sustainable energy sources if it also meant a safer and more reliable supply were also more likely *($p<0.01$)* to pay towards the set-up costs. It is reasonable to assume that these respondents truly desire a safer form of energy provision which is why they were willing to pay more or contribute in order to be able to access a resource that offered this attribute.

Respondents were more likely to pay towards the set-up of a renewable or sustainable energy resource if they would also pay part of the set-up costs for a renewable or sustainable energy source if it meant a more reliable supply *($p<0.01$)*. This association makes sense when you consider the previous variables association with the outcome variable. Safety and reliability are patently two characteristics respondents' desire in an energy source, so much so that they are willing to pay to access an energy source that encompasses these attributes. The association seen between this variable and the outcome variable is as a result of the equal importance these respondents put on these two characteristics.

Outcome Variable 6: Would you pay part of set-up costs for a renewable or sustainable energy supply if it meant: more reliable supply?

The results of the binomial logistic regression using outcome variable 6 are presented in Appendix 1, Section A.1.6.

Respondents from the village of Dihapura were significantly less likely *($p=0.05$)* to pay towards the set-up even if it meant a more reliable supply. This may be because these respondents already consider their current energy sources to be reliable therefore did not see the need to contribute as it is a characteristic that they already possess. Alternatively it could be that these respondents are not in a position to be able to afford to contribute or that reliability is not an important characteristic that they desired in an energy source therefore it is not an enough of an incentive to convince them to contribute towards set-up costs.

The descriptive analysis supports this hypothesis, as household in this village were more likely to use the fuel they do for cooking because it was cheap and because they had a lower mean monthly income than the average household surveyed,

Households were significantly less likely to contribute if they used straw/thatch for roofing *($p=0.01$)* or mud as their main material for flooring *($p<0.01$)*. These materials are generally associated with low income households, which could help explain this association. A household with a low income may be unable to afford to contribute towards the set-up costs even if they wanted to. This hypothesis is supported by the fact that respondents who used these materials were also significantly more likely to have used the main fuels they do for household cooking *($p<0.01$)* or lighting *($p<0.01$)* because they could not afford any other fuels.

Households that had access to paraffin/kerosene for household lighting but chose not to use it were less likely *($p=0.01$)* to pay towards the set-up costs. It is possible that the reason these respondent chose not to use this energy source was because they could not afford to do so. If this was the case it might explain why they were less likely to contribute, simply because they could not afford to do so.

Respondents from households that gave the reason they used the main fuel they did for cooking was because they could not afford other fuels, were less likely *($p<0.01$)* to contribute towards the set-up costs. It is likely that the reason for this is because these respondents cannot afford to contribute which is indicated by the fact that the selection of the energy sources they currently use is restricted by their cost.

Respondents were less likely to pay towards the set-up, even if it meant a more reliable supply, if they were unhappy with their main fuel for cooking because of health concerns *($p<0.01$)*, because it was smoky *($p<0.01$)*, or considered unsafe *($p<0.01$)* or unreliable *($p<0.01$)*.

These associations with the outcome variable may be explained by the significant relationship all of these variables had with the variable 'reason for using main fuel for cooking – cannot afford other fuels' *($p<0.01$)*. These respondents had no choice but to use the fuels they did as they could not afford to use an alternative. If they could not afford to use the fuels they desire it is unlikely that they would be able to afford to contribute.

Households that had access to paraffin/kerosene for cooking but did not use it were less likely *($p<0.01$)* to contribute towards the set-up costs. It is likely that they did not use this energy source as they were aware of the negative health implications associated with its use, or alternatively because they could not afford to. The latter would explain why they were less likely to contribute.

A similar explanation may be given for why respondents who had access to candles for household cooking but chose not to use them were less likely *($p=0.02$)* to contribute. Candles may not be considered a reliable or practical energy source for cooking, but this would not explain why they were less likely to contribute. It is more likely that they simply could not afford to do so.

Respondents whose monthly fuel expenditure included firewood/biomass were less likely *($p=0.01$)* to contribute to the set-up costs. Interestingly these households were also more likely *($p<0.01$)* to have a lower total household income which could explain why they were less inclined to contribute. It may be that they just cannot afford to do so, even if they desired a more reliable fuel which is likely as they were also more likely

($p<0.01$) to indicate the reason they were unhappy with their primary fuel for cooking was because it was ‘unreliable’.

Respondents who obtained biomass fuel for free were less likely *($p<0.01$)* to pay towards setting-up a renewable or sustainable energy source. These respondents may not be able to afford to contribute as inferred by the fact that they had to make use of a fuel that they can obtain for free. They may well desire a more reliable fuel but simply cannot afford to contribute.

Respondents who had heard of renewable or sustainable energy before the study were less likely *($p=0.02$)* to pay towards the set-up. As discussed in previous outcome variables this may be the a result of these respondents having an inaccurate or incomplete understanding of these energy sources, which has led them to form a negative opinion towards their use as a means of delivering modern energy services.

Respondents who did not think any of these technologies would prove beneficial to communities such as their own were unsurprisingly also less likely *($p=0.01$)* to pay towards the set-up costs. This association was unsurprising as if the respondents did not think these technologies would provide any additional benefits there would be no reason for them to contribute towards their set-up.

It is worth noting that despite the benefit of a more reliable supply being outlined it is insufficient to persuade these respondents to contribute. Therefore it is reasonable to conclude that reliability is not a significant characteristic desired by these respondents.

Households with a large number of rooms were more likely *($p=0.02$)* to pay towards the set-up costs. A similar result was seen with other variables that reflect the physical size of the household with respondents from household with more windows *($p<0.01$)* or spread over a higher number of level *($p<0.01$)* all being more likely to contribute towards the set-up. It is reasonable to assume that a larger household will also mean a higher energy demand, as previously discussed this in fact seems to be the case as these household also had higher monthly fuel expenditure. It may be that the energy sources these respondents used may be unable to meet their energy demand therefore they desire an energy source that is more reliable in order to meet all of their energy needs.

Respondents from households where the head of the household was responsible for deciding the fuels used were more likely *($p<0.01$)* to contribute towards the set-up costs of a renewable or sustainable energy source. It’s likely that these respondents were willing to contribute as they desired a more reliable fuel than that which they are currently using. The association with whether the head of household is responsible for the fuels used may be coincidental. A possible explanation could be that these respondents are not involved in the selection of households fuels thus do not have an accurate awareness of their reliability or are unaware of other restrictions such as finances which also affected household fuel selection.

Households where the selection of the fuels used was the responsibility of a male *($p<0.01$)*, or was a shared responsibility *($p=0.01$)* were more likely to pay towards the set-up if it meant a more reliable supply than if a female was in charge of selecting household fuels. This may be an indicator that reliability is not as important a characteristic to females or that alone was not enough of an incentive to persuade them to contribute towards the set-up of an energy source that offers this benefit.

Respondents from household that used concrete as their main material for household roofing *($p<0.01$)* or flooring *($p<0.01$)* were more likely to contribute to the set-up costs. As previously discussed the use of concrete as a building material may imply a larger household with a larger energy demand. It is possible that this is the association being observed, with respondents willing to pay towards the set-up as they desire an energy source that is more reliable which will better able to meet their energy demand.

Respondents whose reason for using the main fuel they did for household lighting was because it was ‘cheap’ were more likely *($p<0.01$)* to pay towards the set-up costs. An explanation for this could be that these respondents had to make use of a cheap fuel because the energy sources available to them are inefficient or unreliable. Therefore they may have had to use larger quantities of fuel in order to complete household tasks. Their willingness to contribute may stem from the belief that by having a more reliable fuel source they will be able to reduce their long term energy consumption thus reduce their energy expenditure.

Respondents whose gave ‘easily available’ as their reason for using the main fuel they did for household lighting were more likely *($p=0.02$)* to pay towards the set-up. These respondents evidently enjoy having access to fuel that is easily available, this could be their justification for contributing towards the set-up costs. By contributing they will have easier access to a modern energy source but also as a bonus it will be more reliable which may remove the need for additional fuels.

Respondents who were happy with the main fuel they used for household lighting were significantly more likely *($p<0.01$)* to pay towards the set-up costs of a renewable or sustainable energy source. Upon further investigation it was found that these respondents were also more likely to have used electricity but also made use of an alternative energy source during power cuts *($p=0.04$)*. This may explain their willingness to contribute. The energy supplied is already in a form they were happy using but it is the incentive of a more reliable supply which encourages them to contribute towards the set-up costs as it may remove the need to use alternatives thus reducing their energy expenditure.

The more electrical lights used by a household the more likely *($p<0.01$)* they were to say ‘yes’ to contributing to the set-up costs. It is plausible that these households have a higher energy demand thus require an energy source that can meet this but also one that they can rely on, this could explain their readiness to contribute.

Household that spent a longer time cooking per 24 hours were more likely *($p=0.01$)* to pay towards the set-up costs. As previously highlighted households that spend a long time cooking could indicate that the fuels being used were inefficient. This could provide and explanation for this association as the respondents may desire a more reliable energy source to overcome this inefficiency.

Respondents who used LPG as their main fuel for household cooking were significantly more likely *($p<0.01$)* to pay towards the set-up costs if it meant a more reliable supply than those who used firewood/biomass as their main fuel. These respondents may have been willing to contribute as they like having access to a modern energy source but may not consider it to be reliable. Alternatively it could be that those who used firewood/biomass are less likely to contribute because they could not afford to do so. This is supported by the findings that households that used firewood/biomass have a significantly lower *($p<0.01$)* total monthly household income and therefore may not have the flexibility in their household budget to be able to afford to contribute even if they desire a more reliable energy source.

Respondents who were happy with their main fuel for household cooking were more likely *($p<0.01$)* to pay towards to the set-up costs. An explanation for this could be because the fuel these respondents were most likely to be using was LPG *($p<0.01$)*, and one reason for using it was because it was easy to use *($p<0.01$)*. They are however also more likely to indicate that they made use of an additional energy source for cooking when the primary fuel was unavailable *($p<0.01$)*. This situation could mean these respondents were already predisposed in favour of using modern energy sources. Their willingness to contribute may stem from their desire to have a more consistent, more reliable supply removing the need to use additional energy sources.

Respondents who used an alternative energy source for household cooking when their primary fuel was unavailable were more likely *($p=0.03$)* to pay towards the set-up of renewable or sustainable energy source. These respondents may be more inclined to contribute as they desire to have access to an energy resource that is consistent and removes the need for alternatives.

Respondents who used paraffin/kerosene as either their primary or additional energy source for cooking were more likely *($p=0.02$)* to contribute to the set-up costs. Similarly respondents who used LPG as either their primary or alternative energy source for cooking were also more likely *($p<0.01$)* to contribute. Both of these variables were associated with the variable 'reason when alternative energy source for cooking used: primary fuel unavailable', what might be being observing then is this variables association to the outcome variable and the respondents motives for contributing as explained above.

The longer fans or air conditioning was used during the summer the significantly more likely *($p<0.01$)* they were to pay towards the set-up if it meant a more reliable supply. This association makes sense as if they are relying on this equipment to cool the house they would want a reliable energy source that enables its continued use.

Respondents were significantly more likely to pay towards the set-up costs if their monthly fuel expenditure included LPG *($p=0.03$)*, paraffin/kerosene *($p=0.01$)* or electricity *($p<0.01$)*. It is reasonable to assume that these respondents were willing to contribute because they are attracted to an alternative energy source that is more reliable. Even if they are happy with the energy sources they were using they may believe that a more reliable supply would be beneficial in the long term. Alternatively these respondents may simply have been happy to contribute to be able to access a modern services from these types (renewable or sustainable) of energy sources. The fact it is more reliable may not be an influencing factor.

The higher a respondents monthly fuel expenditure the more likely *($p=0.01$)* they were to contribute to the set-up costs. These respondents may desire a more reliable energy source believing it may enable them to reduce their total fuel expenditure by not having to make use of multiple energy sources.

Respondents from households which bought all the fuels they used were more likely *($p=0.01$)* to pay towards the set-up costs. The reason for this may be the same as in the previous variable. They desire a more reliable fuel to overcome having to use multiple energy sources for household tasks.

Respondents were more likely to pay towards the set-up of a renewable or sustainable energy source if they owned a refrigerator *($p=0.01$)* or a television *($p=0.03$)*. Appliances such as the refrigerator require a constant energy supply in order to be worthwhile, and so a reliable supply is vital. Although televisions do not require a constant energy supply they are quite costly therefore these respondents probably want a reliable supply in order to get the most out of this appliance.

Respondents from households that had a higher monthly expenditure on food *($p<0.01$)* and education fees *($p=0.02$)* as well as higher total monthly household expenditure (excluding fuels) *($p<0.01$)* were more likely to contribute towards the set-up costs. A logical explanation for this is that these respondents hope that by having a more reliable energy supply they will be able to reduce their fuel expenditure by not having to make use of multiple energy sources. A similar rationalisation may explain why respondents who indicated that their monthly expenditure included clothes *($p=0.03$)* and/or healthcare *($p<0.01$)* were also more likely to contribute to the set-up of a more reliable supply. As discussed above a more reliable supply may reduce fuel expenditure. In both instances this could lead to a greater disposable income which can then be used to improve other areas of day to day life for the household.

Households that had respondents who had heard of solar panels as a means of renewable or sustainable energy generation were more likely *($p=0.03$)* to pay towards the set-up costs of a more reliable supply. These respondents were also significantly more likely *($p<0.01$)* to identify solar panels as an energy source that would be beneficial to communities such as their own. This variable was also significantly associated with the outcome variable with those who thought solar panels would be of benefit being more likely *($p<0.01$)* to contribute towards the set-up.

The relationship between these two variables may explain their association with the outcome variable. It is plausible that the reason these respondents are willing to contribute is because they already believe that these energy sources (solar in particular) will prove beneficial. The increased reliability may be a characteristic they desire, but it may not be an influencing factor as they may already be predisposed towards their use.

Respondents who had a preferred energy source were more likely *($p=0.03$)* to pay towards the set-up costs of a renewable or sustainable energy source. This association may be the result of these respondents also being more likely *($p<0.01$)* to have identified solar panels/power as their preferred energy source and the energy source they believed would be most beneficial. It is possible that what is being observed are the latent effects of the respondents who identified solar panels as a beneficial energy source as they were more likely *($p=0.02$)* to contribute towards set-up costs. These respondents may have been more willing to contribute because they already believed that these energy sources would prove beneficial.

Respondent who believed that renewable or sustainable energy sources should be used over current means of energy generation were more likely *($p<0.01$)* to contribute to the set-up costs. This association is unsurprising as these respondents were already inclined towards the use of these technologies so given the opportunity to access one it would be expected that they would contribute. As discussed before the benefit of a more reliable supply may play a part in this decision but it is impossible to draw an accurate conclusion from this association as to whether it is truly a significant influencing characteristic desired by the respondents.

Households that were willing to switch and pay slightly more for energy from renewable or sustainable energy sources if they knew it was helping protect the local environment were more likely *($p<0.01$)* to pay towards the set-up of a these energy sources if it also meant a more reliable supply. An explanation for this may be that these respondents are not in fact switching for the benefits but instead desire to have access to a form of modern energy. They are willing to pay more or contribute in order to gained access as they are financially able to do so. This may be their true motivation.

Respondents who would switch and pay slightly more for energy from renewable or sustainable energy sources if it also meant a safer and more reliable supply were more likely *($p<0.01$)* to also pay towards the set-up of a renewable or sustainable energy source if it meant a more reliable supply. It is reasonable to assume that these respondents truly desire a more reliable form of energy provision which is why they were willing to pay more or contribute in order to be able to access a resource that offers this attribute.

Respondents were more likely to pay towards the set-up costs for a more reliable supply if they would also pay part of the set-up costs for a renewable or sustainable energy source if it meant a safer supply *($p<0.01$)*. This association makes sense when you consider the previous variables association with the outcome variable. Safety and reliability are clearly two characteristics respondents desire in an energy source so much so that they are willing to pay to access an energy source that incorporates these two attributes. The association seen between these variables and the outcome variable suggests these respondents may be putting equal importance on these two characteristics. However it could also be suggested that these respondents are considering that with a more reliable supply they will be able to reduce the need for alternative fuels which could save them money in the long term. This would imply that reliability is the primary incentive to switch or contribute.

6.3. Discussion

A lack of knowledge in renewable energy can result in a negative attitude, and therefore act as a barrier to the uptake of RETs. This lack of knowledge can come in several forms, including being entirely unaware of RETs, and being miseducated about RETs, both of which were observed in this study.

Whether a respondent was aware of the term ‘renewable energy’ indicated their level of knowledge. A lack of knowledge was mainly associated with respondents’ reasons for using fuels, and whether they were content with said fuels. Respondents that were unhappy with their current fuels tended to be more aware of the term ‘renewable energy’ and had potentially explored alternative options available to them. This would suggest that respondents currently happy with their fuels, despite health, reliability and safety issues, may need to be targeted differently from respondents that were unhappy with their fuels, and willing to switch.

Although household expenditure was not significant in this model, the theme of financial flexibility appeared to be associated with a lack of knowledge of the term ‘renewable energy’. This indicates the importance of not only analysing household income, but also financial flexibility and disposable income; those with little flexibility may not have considered alternatives, assuming they were too expensive.

The outcome variables that questioned a) whether respondents wanted to be provided with RETs and b) whether they wanted to use them over their current means of energy also indicated their attitude towards RETs. As with the previous outcome variable, the variables that were significantly associated with these outcomes were largely financial factors. Respondents with less financial flexibility were less in favour of RETs because of concerns surrounding affordability. In these cases, persons of low income in particular will need to be educated on the long term benefits of these energy supplies. In addition, it suggests financial support may improve communities' attitudes towards the uptake of RETs.

In addition, familiarity appeared to be a key factor in a respondents' decision to use a fuel, despite being unhappy with the negative side effects. This non-progressive attitude in some respondents might act as a significant barrier towards the uptake of RETs and may need to be dealt with in the form of suitable promotion. Conversely respondents already familiar with a modern fuel either through using it themselves, or being aware of individual technologies and their benefits were more likely to want to use RETs. This indicates the potential for education of RETs and their benefits as a key opportunity to contend with the non-progressive barrier.

Despite the concerns surrounding affordability and familiarity, there were indications that change is desired by some and that renewable or sustainable energy sources would be accepted, but a lack of knowledge surrounding these types of energy sources may deter their uptake over more familiar fuels.

The final three outcome variables question whether a respondent would pay part of the set-up costs for a renewable energy supply if it meant a) a cheaper, b) safer or c) more reliable supply. These outcomes examine not only whether respondents are able to accept renewable energy technologies but whether they are also willing to be a part of the process and set-up. This would be an extremely progressive approach to the set-up of a renewable energy source. In addition it examines which factors affect a respondent's need for cheaper, safer or more reliable supplies of energy, enabling the targeting of individuals more accurately. Generally, the factors associated with all three outcomes are based on familiarity with fuels, or based on financial issues.

Financial factors were associated with a respondent's likelihood to pay part of the set-up costs for a cheaper, safer and/or more reliable supply of energy; poorer households, respondents with higher monthly fuel and/or total expenditure were more likely, probably based on the incentives offered of an RET.

Respondents who were less familiar with modern energy services, or had negative attitudes towards RETs and therefore did not think they should be used over current energy means were less likely to pay towards set-up costs. Conversely, respondents with prior positive experiences or knowledge of modern energy sources and RETs made them more likely to contribute.

6.4. Summary

Several factors were identified including time spent cooking, total household income, total household expenditure, awareness of RETs, which could be used as indicators for assessing respondents attitudes towards the use of renewable energy sources. These indicators could also be used to improve acceptance and uptake of these technologies by identifying individuals or groups associated with specific barriers which would then allow targeted action to be taken to overcome said barriers.

Generally the factors to address are financial concerns and lack of familiarity with the benefits of modern energy access and RETs. Suitable education, financial assistance will improve the progressive attitude of a community, improving opportunities and removing barriers for the uptake of RETs.

However, the work contained in this chapter and the two preceding it only cover the social barriers that exist. It is equally important that the technology is suitable for use in this area and that it will not have a detrimental impact upon implementation in order to properly assess this a life cycle assessment (LCA) of potential solutions will be carried out in Chapter 7.

Chapter 7. Impacts & Feasibility Of Applying Decentralised Energy Storage Systems In Rural Communities.

7.1. Introduction

There are several quantifiable factors associated with RETs which can vary significantly between different projects and could have a substantial effect on the extent of negative impacts. These factors include location (of site establishment and technology manufacture), methods of manufacturing, resource inputs and technologies utilised, methods of transportation, size and capacity of project, use of additional equipment, in particular batteries for energy storage which are essential in decentralised systems, and finally the life span of the project (Nugent & Sovacool 2014).

It is important to consider these impacts in order to be able to take action to mitigate them, ensure the most appropriate technology is applied and avoid potential barriers. One method of doing this is through the use of life cycle assessment (LCA), which allows the assessment of the potential environmental impacts associated with a product, process or activity across it life cycle which result from material and energy requirements and emissions (Guinée *et al.* 2002, Niederl-Schmidinger & Narodoslawsky 2008).

These impacts can affect the feasibility of using an RET. The advantages and disadvantages of various RETs which could provide a means by which modern energy access could be delivered to rural communities and also lend themselves to decentralised energy generation have been discussed previously (Chapters 2.1.1 and 2.1.2). Geothermal energy, hydropower and bioenergy have been ruled out as impractical for use in delivering modern energy services to rural communities in India, due to several issues outlined in Chapter 2.1.2.

The RETs which are potentially best suited to deliver the modern energy needs of rural and remote communities in developing countries are solar panels and wind turbines. Their ease of installation, modular nature and minimal impacts compared to other technologies means they lend themselves well to this role (Chauhan & Saini 2014).

Solar power in particular has been highlighted to have excellent potential in India as the majority of the country has an annual potential in excess of 1700 kWh/m^2, or >4.7 kWh/m^2 per day (MNRE 2009).

An issue that arises with the use of all RETs (and particularly RETs that generate electric energy) when used for decentralised energy provision is how the energy that is generated can be stored, especially as generation can be intermittent, specific to certain times of day or occur during off peak times (Dubey *et al.* 2013, Evans *et al.* 2012, Ibrahim *et al.* 2008, Yekini Suberu *et al.* 2014). The methods of energy storage are varied and could also affect the barriers to and impacts of an RET project. In order for RETs to be considered as reliable as conventional centralised generation, energy storage is a critical factor (Kousksou *et al.* 2014, Nair & Garimella 2010, Yekini Suberu *et al.* 2014).

In the case of RETs that produce electrical energy, storage entails converting the energy generated by RETs into a different form which can then be converted back when needed (Evans *et al.* 2012, Ibrahim *et al.* 2008). Generally electrical energy storage systems can be split into three groups, electrical, mechanical and chemical (Evans *et al.* 2012, Kousksou *et al.* 2014) and were discussed in more detail in Chapter 2.1.1.

Chemical storage systems (in particular conventional battery technologies) are considered the best option available for storing small to medium quantities of energy (Mohd *et al.* 2008). The maturity of battery technologies, their ease of use and high energy densities make them ideal for small scale energy storage as part of decentralised energy systems (Nair & Garimella 2010).

The main difference between varying battery systems are the materials used for the electrolyte and electrodes (Kousksou *et al.* 2014, Yekini Suberu *et al.* 2014). Batteries that are currently available and have the potential for use in small scale decentralised energy systems include lead-acid (PbA), nickel-cadmium (NiCd), nickel-metal hydride (NiMH) and lithium ion (Li-ion) (Kousksou *et al.* 2014, Nair & Garimella 2010).

PbA batteries are the most mature of all battery technologies. Their low cost, maintenance requirements and low self-discharge make them an ideal energy storage solution (Kousksou *et al.* 2014, Nair & Garimella 2010, Yekini Suberu *et al.* 2014). Their drawbacks however are limited cycle life, failure due to deep and continuous cycling, and performance issues at low and high ambient temperatures and in addition the acid electrolyte and lead content can result in major negative environmental impacts, particularly if not disposed of correctly (Evans *et al.* 2012, Hadjipaschalis *et al.* 2009, Kousksou *et al.* 2014, Nair & Garimella 2010).

NiCd batteries in comparison to PbA batteries have longer life cycles, higher energy densities and lower maintenance requirements (Kousksou *et al.* 2014, Nair & Garimella 2010). However the use of Cd and Ni means that these batteries are associated with high costs (Kousksou *et al.* 2014, Yekini Suberu *et al.* 2014). They are also associated with a high level of self-discharge and a range of impacts and hazards because of the toxic heavy metals they contain, in particular cadmium (Cd) (Evans *et al.* 2012, Nair & Garimella 2010, Rahman *et al.* 2012, Yekini Suberu *et al.* 2014). The EUs Restriction of Hazardous Substances Directive (RoHS) which came into effect in 2006, and the later updated RoHS 2 directive restrict the use of Cd and Pb in certain electronics and electrical equipment (European Parliament 2003, European Parliament 2011). Although batteries are not covered by these directives, it is an indication of the desire to reduce the use of these metals which in the future could lead to restrictions on the production and use of both NiCd and PbA batteries.

NiMH batteries are considered the alternative to NiCd batteries because of their improved performance but most notably the reduced adverse environmental impacts due to the lack of toxic substances (Kousksou *et al.* 2014, Nair & Garimella 2010). The energy density of NiMH batteries are also higher than NiCd batteries, however like NiCd batteries, they suffer from a high level of self-discharge making them impractical for long term energy storage (Kousksou *et al.* 2014, Nair & Garimella 2010)

The use of Li-ion batteries is associated with very high investment costs and complicated energy management systems (Ahmadi *et al.* 2014). However they have the highest energy density of the batteries discussed, very low self-discharge rates and have been shown to have energy storage efficiencies close to 100.0% (Evans *et al.* 2012, Kousksou *et al.* 2014, Nair & Garimella 2010, Yekini Suberu *et al.* 2014). The cycle life of a Li-ion battery is affected by temperature with it being shortened at higher temperatures. Furthermore repeated deep discharges can also result in shorting of the batteries life (Díaz-González *et al.* 2012, Kousksou *et al.* 2014).

Although batteries are the most efficient and suitable means by which the energy generated from RETs can be stored and utilised in decentralised energy systems, they are associated with a range of environmental and economic issues.

Their high costs and short life spans could make them financially unviable for some of the poorest communities. Furthermore because of their hazardous content, if not disposed of correctly, they could result in significant negative social, economic and environmental impacts (Borges Neto *et al.* 2010).

The Clean Development Mechanism (CDM) (which allows developed countries to earn 'certified emission reduction' (CER) credits by contributing to or implementing emission reducing projects in developing countries (Akella *et al.* 2009, UNFCCC 2014)) could facilitate a means by which these costs could be avoided with developed countries absorbing them in exchange for the CER credits earned. The life span of a battery is affected by various factors including depth of discharge and rate of discharge. It is therefore feasible that under the correct conditions, the cycle life of these batteries could be considerably increased (Ahmadi *et al.* 2014, Broussely 2010).

Another important factor that is sometimes overlooked is the contribution to GHG emission from the materials and energy requirements of the manufacture and processing of these batteries. These emissions should be attributed to the total carbon footprint of an RET project and therefore included when calculating the payback time of a project before it starts having a positive offsetting effect on carbon emissions.

A proposed method of avoiding these impacts is through the repurposing of batteries from other areas, in particular of Li-ion batteries from the automotive industry (Faria *et al.* 2014). Faria *et al.* (2014) highlighted that even when these batteries are no longer suitable for use in electric mobility they could still be used as means of stationary energy storage. Their suitability for integration into renewables systems for storage applications has been highlighted in several recent studies (Ahmadi *et al.* 2014, Richa *et al.* 2014, Shokrzadeh & Bibeau 2012).

Li-ion batteries from the automotive industry typically have a life span of between 8 – 10 years, but are considered to have reached their end of life (EOL) when they are degraded to only 80.0% of their initial capacity (Ahmadi *et al.* 2014, Richa *et al.* 2014, Williams & Lipman 2010). Extending the service life of these batteries may offer significant economic and environmental benefits through avoiding the need for virgin material extraction and processing of new batteries (Faria *et al.* 2014, Wang *et al.* 2014b). As the demand for electric and hybrid vehicles increases, as will the volume of EOL Li-ion batteries that need to be disposed of (Richa *et al.* 2014, Wang *et al.* 2014b, Wang *et al.* 2014c).

In this chapter the suitability of different means of electrical energy storage for use in decentralised energy projects in developing countries are considered and the environmental consequences which can be associated with these projects is assessed using LCA methods after taking energy demand into account. In addition, the use of repurposed batteries is examined to explore the feasibility of their use and any offsetting effect they may contribute.

7.2. Aims & Methods

The aim of this chapter was to access and quantify the potential environmental impacts which could be associated with a renewable or sustainable energy system as a result of the need to include decentralised energy storage to ensure its feasibility.

This is achieved via the completion of a LCA which examines and compares the four main chemical storage systems available, lead-acid (PbA), nickel-cadmium (NiCd), nickel-metal hydride (NiMH) and lithium ion (Li-ion). In addition an evaluation of the repurposing of EOL Li-ion batteries from automotive uses is completed to assess the offsetting benefits second life batteries can have.

The LCA considered the cradle-to-gate emissions emitted during the production of these batteries, and the offsetting effect repurposing Li-ion batteries can have on reducing the carbon footprint of a decentralised RET system.

The methods and approaches undertaken in the completion of the life cycle assessment completed in this chapter can be found in Chapter 3.2, with the International Organisation for Standardisation (ISO) standards for LCA (ISO 14040 and 14044) used as a guide for this studies completion.

As no LCA can be completely exhaustive it is necessary to define the limits of any assessment (Van den Bossche *et al.* 2006).

There are a range of limitations and caveats which must be taken into consideration for this study which relate to the LCA methodology. Firstly it is important to remember that LCA is only a measure of potential impacts, they are not specific in time and are centred on an arbitrarily defined functional unit. They also consider all processes to be linear.

This study made use of results from LCAs available in the literature, and despite following the same goal and scope, it is impossible to ascertain if all of these studies have been completed in the same way or incorporated the same aspects of battery production. The broad scope of an LCA can be the biggest limitation, as it can often only be achieved at the expense of simplifying certain aspects of a life cycle (Guinée *et al.* 2002).

As this study also made use of mean values calculated from the literature for certain characteristics of a battery (for example energy density and emissions), there is potential for variation between the calculated and true results. The specific effects that this variation could have on specific aspects of an LCA are discussed later, but it is important to note as these variations could have a significant effect on the final findings and conclusions drawn from any assessment.

Any LCA also involves a number of assumptions. It is important to make sure these assumptions are clearly outlined. The assumptions for this study have been outlined in Chapter 3.2.2. Some of the major assumptions include the calculation of the per capita energy demand for each of the three scenarios of rural Indian communities. The properties of the repurposed Li-ion batteries and the life span of hybrid vehicles.

This LCA has also not taken into account the potential impacts of other aspects of a batteries life cycle which could have a significant impact on their suitability to be used as a decentralised storage system. Areas that are not covered include the energy management systems, transportation, life span of the battery and final EOL scenarios. These aspects were not included in the scope of this study as there is considerable potential for substantial variation which makes accurately quantifying any associated impact extremely difficult.

7.3. Results

Life Cycle Inventory Analysis

7.3.1. Atmospheric Emissions & Energy Densities of Battery Technologies

The volumes of atmospheric GHGs and other selected pollutants that are emitted during the production of the selected batteries and the total GWP per kg of battery are presented in Table 7.1 There are different levels of emissions associated with the production of different batteries. The more established batteries (PbA, for example) have lower GWP/kg compared to more modern battery types (Li-ion).

Table 7.1: Total atmospheric emissions from cradle-to-gate analysis of various battery technologies and aggregated life cycle GWP.

		Emissions to Atmosphere per kg of battery≠						GWP
		VOC g/kg	NOx g/kg	PM g/kg	CH_4 g/kg	N_2O g/kg	CO_2 kg/kg	kg CO_2e/kg#
Battery Type	PbA	0.7	0.0047	4.7	3.9	0.0	3.2	3.53
	NiCd	2.5	0.0192	12.3	8.6	0.1	9.6	10.35
	NIMH	1.2	0.0176	18	19.6	0.2	13.6	15.30
	Li-ion	0.9	0.0145	19.6	13.7	0.1	10.8	11.98

≠ Adapted from (Sullivan & Gaines 2012)
#GWP equivalency figures from (IPCC 2013)

Figure 7.1 presents the relative energy densities of each battery. PbA batteries have the lowest energy density at 34.72 Wh/kg, NiCd batteries 48.75 Wh/kg, NiMH batteries 66.50 Wh/kg and Li-ion batteries have the highest, at 116.43 Wh/kg. A repurposed EOL Li-ion battery has a reduced energy density of 93.14 Wh/kg due to degradation.

An independent-sample t-test was conducted to compare the energy densities of the different batteries, the results are summarised in Table 7.2. The energy densities of all of the batteries were found to be significantly different from one another with the exception of NiCd and NiMH, which when compared were not found to be significantly different *($t(8.07) = 2.21$, $p = 0.06$)*.

Figure 7.1: Relative energy densities of varying chemical energy storage systems.

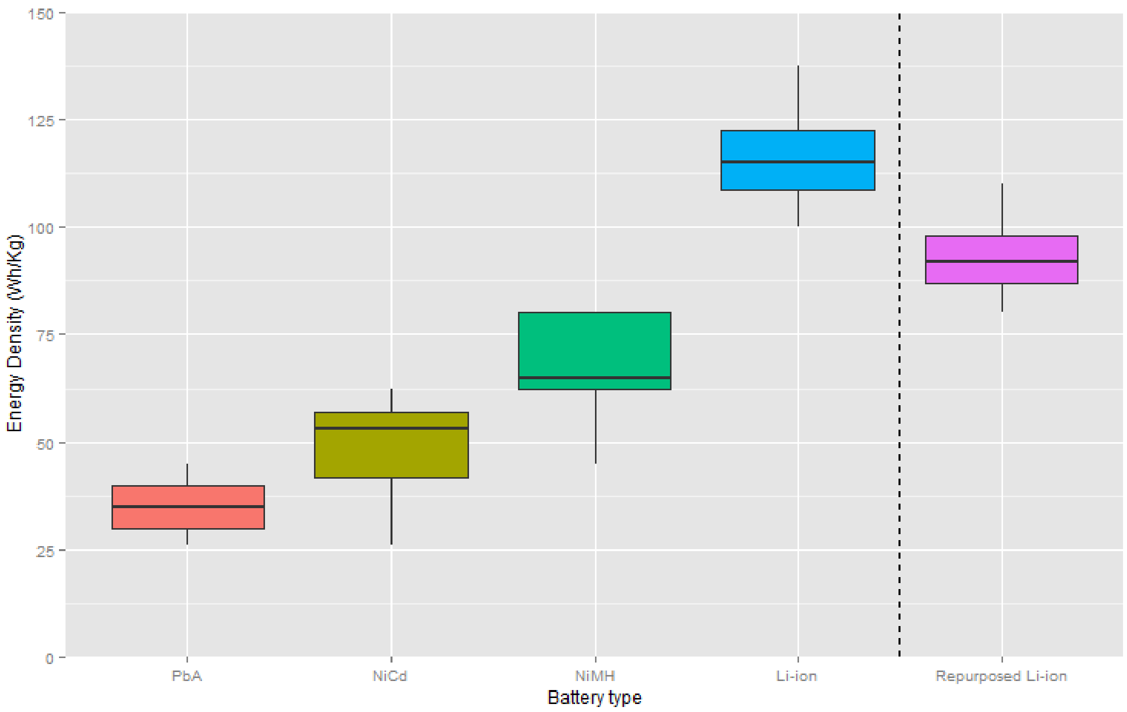


Table 7.2: p values from independent-sample t-tests comparing different battery energy densities#

Battery type	PbA	NiCd	NiMH	Li-ion	Repurposed Li-ion
PbA	1.00				
NiCd	0.02	1.00			
NiMH	<0.01	0.06	1.00		
Li-ion	<0.01	<0.01	<0.01	1.00	
Repurposed Li-ion	<0.01	<0.01	0.01	<0.01	1.00

#Full results in Appendix 4

7.3.2. Carbon Saving From First Life Of Li-Ion Batteries

During the ‘use phase’ of its first life, a Li-ion battery enables a carbon saving of 0.17 kg CO_2/km (Equation 3.1: Part A) when compared to the emission produced by a standard passenger vehicle. This would result in a total carbon saving of 33.38 tCO_2 based on the EUs specified service life target for a passenger vehicle (Equation 3.1: Part B).

To offset the carbon debt accumulated during the production of its Li-ion battery, a hybrid vehicle would need to travel a total distance of approximately 18,091 km (Equation 3.2: Part A). This equates to the carbon debt per kg of battery being offset after 71.79 km (Equation 3.2: Part B).

7.3.3. Battery Mass Requirements To Meet Per Capita Energy Demand

The national per capita energy demand in India’s rural households is 1.70 kWh per day. However, the per capita energy demand of the archetypal household from the rural village of Uddhar was only 1.43 kWh per day, and the per capita energy demand for the state of Orissa was 1.05 kWh per day.

Table 7.3 outlines the mass of battery that would be required to store sufficient energy to meet these per capita energy demands over varying time scales. The battery mass required to meet the per capita energy demand varied for each scenario, with battery masses highest in scenario 1 followed by scenario 2 and scenario 3. Under all scenarios PbA batteries were the batteries for which the largest mass was required in order to meet the energy demand for the set time period. Similarly Li-ion batteries were in all scenarios the batteries that required the smallest mass in order to meet energy demand.

The battery masses range in size depending on timeframe of per capita demand. These masses would affect the feasibility of a project.

Table 7.3: Mass of battery (by type) required to store and supply per capita energy needs under varying scenario of demand from rural Indian communities.

		Battery mass required to meet per capita energy demand (kg)								
		Scenario 1			Scenario 2			Scenario 3		
		Per Month	Per Week	Per Day	Per Month	Per Week	Per Day	Per Month	Per Week	Per Day
Battery Type	PbA	1,373.27	343.32	49.05	1,156.37	289.09	41.3	849.43	212.36	30.34
	NiCd	978.11	244.53	34.93	823.62	205.91	29.42	605.01	151.25	21.61
	NiMH	717.04	179.26	25.61	603.78	150.95	21.56	443.52	110.88	15.84
	Li-ion	409.55	102.39	14.63	344.86	86.22	12.32	253.32	63.33	9.05
	Repurposed Li-ion	511.93	127.98	18.28	431.08	107.77	15.4	316.65	79.16	11.31

When compared to virgin Li-ion batteries, the mass of repurposed Li-ion batteries needed to store and supply the same per capita energy demand under the different scenarios is approximately 25% greater despite only 20% degradation in energy density.

7.3.1. GWP & Other Emissions Of Required Batteries

Table 7.4 presents the prospective total GWP attributed to each battery as a result of GHGs emitted during the production of a battery capable of storing and supplying sufficient energy to meet the per capita energy demand per day of India's rural communities for each scenario.

Despite higher GWP/kg (Table 7.4), the total GWP of the more 'modern' Li-ion batteries are very similar to the older more established PbA batteries. For example under Scenario 1 the GWP associated with the PbA battery required to store and supply the per capita energy demand for 1 day is 0.17 tCO_2e, the Li-ion battery total GWP 0.18 tCO_2e for the same time period.

NiCd and NiMH batteries also have very similar total GWP values to each other, but have much higher total GWP values when compared to PbA or Li-ion batteries under all of the scenarios presented.

Of all of the GHGs measured, CO_2 makes the largest contribution to overall total GWP. Table 7.4 outlines the contribution CO_2 makes to each total GWP. The level of contribution for individual batteries within each scenario ranges from 85.7% to 95.5%.

The production of NiCd batteries results in the largest average CO_2 contribution to final GWP across all scenarios with an average contribution of 94.4%. Li-ion battery production has the lowest average CO_2 contribution at 88.8%.The average CO_2 contribution to GWP of NiMH battery production was 89.8% and PbA batteries 90.6%.

In addition to GHGs, the volumes of other important pollutants emitted during the production phase of different battery types, of different masses, capable of meeting the per capita energy demand per day for the different scenarios are presented in Table 7.5.

Total VOC emissions were consistently higher for the production of the NiCd batteries across all three scenarios, reflecting their high per kg emission rate (2.5 g/kg (Table 7.1)). NiMH and Li-ion batteries however, despite having a higher per kg emission rate (1.2 g/kg and 0.9 g/kg respectively (Table 7.1)) than PbA batteries (0.7 g/kg) both have lower total VOC emission across all scenarios.

Table 7.4: GWP associated with batteries of varying size required to meet per capita energy demand for different scenarios of rural India and contribution of CO_2 emissions towards total GWP.

		GWP of battery required to meet per capita energy demand (tCO_2e)					
		Scenario 1		Scenario 2		Scenario 3	
		Per Day	CO_2	Per Day	CO_2	Per Day	CO_2
Battery Type	PbA	0.17	0.16	0.15	0.13	0.11	0.10
	NiCd	0.36	0.34	0.3	0.28	0.22	0.21
	NiMH	0.39	0.35	0.33	0.29	0.24	0.22
	Li-ion	0.18	0.16	0.15	0.13	0.11	0.10
	Repurposed Li-ion	0.22	0.20	0.18	0.17	0.14	0.12

Table 7.5: Emissions of VOC, NO_x and PM pollutants associated with batteries of varying size required to meet per capita energy demand for 1 day for 3 scenarios of rural India.

		Emissions from battery required to meet per capita energy demand (g/kg)								
		Scenario 1			Scenario 2			Scenario 3		
		VOC	NOx	PM	VOC	NOx	PM	VOC	NOx	PM
Battery type	PbA	34.33	0.23	230.51	28.91	0.19	194.10	21.24	0.14	142.58
	NiCd	87.33	0.67	429.67	73.54	0.56	361.81	54.02	0.41	265.77
	NiMH	30.73	0.45	460.95	25.88	0.38	388.15	19.01	0.28	285.12
	Li-ion	13.16	0.21	286.68	11.08	0.18	241.40	8.14	0.13	177.33
	Repurposed Li-ion	16.46	0.27	358.35	13.86	0.22	301.75	10.18	0.16	221.66

A similar pattern is seen with the level of total NO_x emissions. However only Li-ion batteries result in lower NO_x emissions than PbA batteries across all scenarios despite having a higher g/kg emission rate (0.0145 g/kg compared to 0.0047 g/kg (Table 7.1)). Again NiCd batteries result in the highest total NO_x emissions across all three scenarios. The volume of NO_x emitted by the production of all batteries is substantially lower than the volumes of the other pollutants emitted.

Despite having the highest PM emissions per kg (19.6 g/kg) Li-ion batteries across all scenarios had the second lowest total PM emissions. PbA batteries had the lowest total, and NiMH batteries the highest. NiCd batteries have a per kg PM emission rate 31.7% lower than NiMH batteries, however the total PM emission of NiCd batteries was only 6.8% lower when compared to the total from NiMH batteries under the same scenarios (Table 7.5).

7.4. Discussion

7.4.1. Environmental Impacts Assessment

This study assessed the environmental impacts (through quantification of CO_2, other GHGs emissions and other pollutants) of battery production after accounting for the battery mass required to fulfil energy demands in rural communities.

The means for the estimated volumes of each pollutant/GHG emitted were taken from a variety of studies exploring the cradle-to-gate life cycle of the various batteries reviewed by Sullivan & Gaines (2012). Although the means of these datasets were used in this study, the range of volumes of these emissions varied considerably and thus could alter the estimated volumes of each pollutant/GHG emitted. These variations may be due to differences in methodology between different studies.

Differences in the LCA scope and boundaries of each of the studies that Sullivan & Gaines (2012) reviewed are important to consider as these can significantly affect the final output. These differences could alter the degree by which an impact is measured and thus the significance of that impact within a batteries life cycle.

For example, the CO_2 emissions associated with the production of PbA batteries ranged from 1.1 - 6.4 kg/kg (Sullivan & Gaines 2012). If these values were used to estimate the total CO_2 emission from the production of a PbA battery required to meet the energy demand under Scenario 1 for 1 day, the total CO_2 emissions could range from 53.95 - 313.89 kg. These values are substantially different to the mean total CO_2 emissions of

156.95 kg, highlighting the difficulties of accurately assessing the emissions produced during battery production and how variation of the scope of an LCA can affect the final impact assessment.

A range was observed in the total potential emissions for all the impact categories assessed (VOC, NOx, PM, CH_4, N_2O and CO_2) for all of the batteries evaluated (PbA, NiCD, NiMH and Li-ion). An impact that this could have within the context of this study is that the GWP/kg value calculated for each battery may have been over or under estimated.

Although variable, the production of each battery type assessed in this study have previously been shown to emit VOC, NOx, PM, CH_4, N_2O and CO_2 (Sullivan & Gaines 2012) which can have all been associated with a wide range of local and global detrimental impacts. The impacts and adverse effects associated with the release of anthropometric GHGs have been well documented (see Chapter 1.3).

VOC alone can lead to various negative human health impacts due to many exhibiting toxic effects and contribute to stratospheric ozone depletion (Hester & Harrison 1995, Kampa & Castanas 2008, Luo *et al.* 2011, Tyler Miller & Spoolman 2008). Furthermore in combination with NO_x, emissions can result in the more localised impact of photochemical smog formation which has also been linked to a variety of human health impacts (Kampa & Castanas 2008, Tyler Miller & Spoolman 2008). The emissions of PM are also associated with more localised impacts, leading to local air pollution which can result in acute respiratory infections (IEA 2007)

The energy density of each battery was calculated by compiling the values from a range of different literature sources and calculating the mean. As discussed previously, using values from different studies may result in a large range due to study methodology differences which could have impacted the final calculated energy densities in this study. The energy densities of the different battery types were found to be significantly different from one another (with the exception of NiCd vs NiMH). This highlights that despite the variation observed in the energy densities of individual battery types, they are still distinctly different from one another.

The mass of the battery required to store and supply energy demand is inversely proportional to the energy density and thus varies depending on battery type. Although the production of Li-ion batteries is associated with a significantly higher GWP per kg (11.98 kg CO_2e/kg) compared to PbA batteries (3.53 kg CO_2e/kg), because of their higher energy density (116.43 Wh/kg compared to 66.5 Wh/kg), a much smaller battery is required to store and supply the same energy. This ultimately means that the total CO_2e that can be associated with an RET system from the use of Li-ion batteries for energy storage is very similar to that of PbA batteries.

The maturity of PbA batteries means that the process of their manufacture has been continuously refined to make it more efficient. It is therefore feasible that as advancements are made in the production of Li-ion batteries, a reduction in CO_2 emissions may be observed making them an environmentally better option than PbA.

A similar observation can be made when comparing NiMH and NiCd batteries. The higher energy density of NiMH batteries (66.5 Wh/kg compared to 48.75 Wh/kg) means that ultimately a smaller mass battery is required to store and supply the required energy demand. This results in a similar GWP value despite NiMH batteries having a higher GWP per kg than NiCd. Advancements in the production of these batteries could lead to a lower GWP/kg. Furthermore when combined with their reduced adverse environmental impacts, due to the lack of toxic content, NiMH batteries may prove to be an overall better energy storage solution than any of the other batteries.

Increased energy density may not only result in reduced emissions; having a smaller storage system may also mean a smaller impact at the site of set-up as the installation will have a smaller footprint resulting in less competition for space and less habitat destruction.

Although the required battery mass is dependent upon energy density, it is also determined by energy requirements. In Chapters 4 and 5, rural household energy demand was identified based on data collected from a single village (Chapter 4) and a broader state wide study (Chapter 5). These, coupled with the national figures for India from The World Bank (Khandker *et al.* 2010) have enabled the comparison of household energy requirements for three different scenarios: village level, state level and national level. In this study, the daily per capita energy demand based on national data (1.70 kWh) was higher than the daily per capita energy demand based on data for a single state (1.05 kWh) or single village (1.43 kWh).

The national figure is derived from a study that surveyed rural household from a range of villages regardless of their size. The only criteria for their inclusion was that the India census classed them as being in rural areas. The survey that the state and village figures are based on however focused on small rural villages with a population of 2,500 or less, as the majority of India's rural population reside within villages of this description (ORGC India 2001d). The difference in the boundaries of these studies could explain the disparity between these values.

Furthermore the study found that the per capita energy demand based on a single village was higher than the per capita demand based on a single state. This could be because this particular village has an unusually high energy demands. Alternatively, the energy requirements for the villages selected within the state of Orissa may have been atypically low. Ultimately however, this highlights that in some circumstances a top down approach to estimating energy demand may not always be appropriate. To explore this further, the energy requirements of several villages within several states would need to be assessed.

In this study The World Bank's estimate for per capita energy demand in rural communities (Khandker *et al.* 2010) was used for the national scenario (Scenario 1). Obtaining accurate per capita energy demand for India's rural communities was difficult as in almost all cases per capita energy demand is reported as a national statistic for a total population and not sub divided into rural/non-rural populations. Even when national per capita energy demand is reported, the values can vary depending upon the methods by which it is collected and the assumptions used. For example, India's per capita energy demand has also been estimated to be 17.23 kWh/day according to the EIA, but 21.25 kWh/day according The World Bank (EIA 2014, The World Bank 2014).

Scenarios 2 and 3 used in this study were created using data available from The World Bank, which was used in their own study, outlining the efficiency of different fuel types which allowed end energy use to be determined from total fuel use. In addition, estimations from The World Bank of total energy consumption of different appliances were used. Although this information enabled a better direct comparison between the 3 scenarios, the actually end energy consumed, especially by appliances, could vary substantially, which would ultimately change the final per capita energy demand calculation.

The combination of energy density and energy demand determines the mass of battery required. As the battery mass selection is dependent upon the correct forecast of energy demand, inaccuracies in the energy requirement assumptions would result in inappropriately sized batteries being selected.

The mass of a battery that would be required to meet the per capita energy demand for 1 day under each scenario varies between each battery type because of the difference in energy density.

Across all three scenarios the battery type for which the largest mass is required in order to store the required per capita energy demand is consistently PbA batteries. Similarly the battery type for which the smallest mass of battery is required to meet the per capita energy demand across all three scenarios is Li-ion batteries.

As Scenario 1 presents the largest per capita energy demand it is unsurprising that the mass of each battery type required to store and supply this demand for 1 day is also the highest when compared to the same battery types across the three scenarios. Correspondingly, the mass of the batteries required to meet the per capita energy demand for 1 day outlined under Scenario 3, which is the scenario with the smallest per capita energy demand, are the smallest across all three scenarios.

This increase in mass will mean an increase in the cost of the battery system. Although at present PbA batteries are noted as being the cheapest suitable option (Kousksou *et al.* 2014, Nair & Garimella 2010, Yekini Suberu *et al.* 2014), if a larger battery is required its cost could become comparable to the more expensive, but higher energy dense batteries such as Li-ion. Furthermore, as previously highlighted, the manufacture of PbA batteries is a well-refined process whereas there are still opportunities to further refine the production of the other batteries types. This could contribute to reducing their overall production cost which ultimately may result in PbA batteries becoming the most expensive systems in terms of cost relative to energy density.

In reality, the energy demand a battery system will be required to store will be greater than 1 day in order to be able to mitigate any prolonged periods where generation is disrupted. However, as the mass of a battery increases it is likely that its size will too. As these results relate to per capita and the findings of the two surveys completed in the previous chapters showed that household size can range from 2-30 permanent occupants, the actual mass of battery required to meet a households energy demand could be considerably larger and would need to be determined on a case by case approach. The larger a battery the more problems that could arise, a lack of available land is already an existing barrier to the introduction of RETs (Mitchell *et al.* 2011), the additional requirements for battery installation could further exacerbate this barrier.

Having a battery system that stores more energy than is required to meet the energy demand between periods when recharging take place can also have positive effects on a batteries cycle life. This is because storing more than is required reduces the chance of regular deep discharge of the battery. Sullivan & Gaines (2010) showed that changes in the level of discharge can change the maximum number of cycles a battery can go through. Thus by using a battery that can last several days, complete discharge is avoided and the shorter depth of discharge cycles can prolong a batteries life.

The larger a battery, the more it competes for space and the increase in the chance that its installation could lead to detrimental impacts such as habitat loss both of which have been identified as barriers to the introduction of RETs (Moomow *et al.* 2011, Painuly 2001). The use of batteries with higher energy densities could mitigate these issues, as a smaller battery system could be used whilst still meeting the necessary energy demand.

An increase in mass will also mean an increase in the level of emissions which could be attributed to the battery from its production. It is therefore important to accurately estimate the level of energy demand to minimise the potential impacts from these emissions.

This is reflected in the results where the emission levels of the various pollutants are much higher in Scenario 1 compared to Scenario 3. However because of the influence of energy density, the battery type with the lowest emission levels per kg will not necessarily result in the lowest total emissions when used to meet per capita energy demand under each scenario.

Despite having the lowest VOC, and NO_x emissions per kg, PbA batteries did not have the lowest total emissions when evaluated against the mass of a battery that would be required to meet the per capita energy demand outlined under any of the scenarios. PbA batteries did however have the lowest PM emissions compared to all other batteries across all of the scenarios.

Li-ion batteries had the highest PM emissions per kg but the second lowest total PM across the three scenarios. This is because these batteries also have the highest energy density and therefore a smaller mass of battery is required to store the required energy demand. This also explains why Li-ion batteries despite not having the lowest VOC and NO_x emissions per kg did however have the smallest total VOC and NO_x emissions across all three scenarios.

This is also observed with total GWP, where Li-ion batteries despite having one of the highest GWP per kg have almost the lowest associated total GWP across all three scenarios.

Across all the batteries examined CO_2 emissions were the major contributor to GWP, with total contribution ranging from 85.7% to 95.5%. CO_2 has been identified as the single most problematic anthropogenic GHG because of the quantities that are being released into the atmosphere (IPCC 2013). It therefore seems sensible that action to mitigate this particular GHG should be taken where possible.

The inventory analysis shows that the repurposing of Li-ion batteries from the automotive industry presents a means by which the impacts resulting from the emission of GHGs could be successfully mitigated. It is more than feasible that these batteries could be used for energy storage in a decentralised energy system; several studies have also outlined their suitability (Ahmadi *et al.* 2014, Faria *et al.* 2014, Richa *et al.* 2014, Shokrzadeh & Bibeau 2012).

In order to store and supply sufficient energy to meet the per capita energy demand of India's rural communities for three days (5.11 kWh based on Scenario 1), a repurposed Li-ion battery system of at least 54.85 kg would be needed. During its production this system would have resulted in the emission of 0.66 tCO_2e of GHGs. However, as this battery has already been used in a hybrid passenger vehicle it will have already paid back some of its "carbon debt".

According to the findings of the inventory analysis, a hybrid vehicle would pay back this debt after only 3,937 km, far less than the 200,000 km expected during the vehicles service life. There is therefore potential for these batteries to accumulate a carbon credit during their first life (32.72tCO_2e in this scenario) which could then carry over to an RET system.

So despite the loss in capacity during their first life which necessitates the need for a larger system when using repurposed Li-ion batteries, overall the process may result in positive effects by avoiding the need to produce new virgin batteries and reducing the overall carbon footprint of a decentralised energy system.

7.4.2. Economic consideration

Cost has been widely identified as a major barrier to the expanded uptake of decentralised RET systems (Dombi *et al.* 2014, Painuly 2001, Reddy & Painuly 2004) and was also shown to be a significant concern by respondents in rural energy surveys completed in Chapters 4 and 5. As with RETs, the costs associated with the batteries used for decentralised energy storage will have a major impact upon their uptake, as well as the feasibility of an entire RET project.

Despite the perceived environmental benefits of using Li-ion batteries, their high capital costs could render them an unfeasible solution as the target communities simply cannot afford the initial investment costs which have been shown to be over ten times as high as the capital costs of PbA batteries (Diouf & Pode 2015, Evans *et al.* 2012).

Nair & Garimella (2010) showed however, that the cost of energy from Li-ion batteries ($2.065/kWh) was notably lower than NiCD ($2.399/kWh) and NiMH ($2.279/kWh) and slightly lower than PbA ($2.069/kWh) batteries across their entire life cycle (Nair & Garimella 2010). This is largely due to the significantly lower operating costs associated with the use of Li-ion batteries (Nair & Garimella 2010).

The longer cycle life and lower operating costs of Li-ion batteries may mean it is better to invest in these types of batteries despite higher initial investment costs (Diouf & Pode 2015, Nair & Garimella 2010). However the initial expense may present too much of a barrier, which when combined with the other costs of a decentralised RET system may deter stockholders despite the long term benefits, prompting them to select a form of energy storage which is cheaper, or eschewing the use of a RET system all together.

The cost attributed to RET systems as a result of the energy storage system used will not only be dependent on the system employed but also its scale. Although larger systems will cost more overall, it is possible that to an individual they may be significantly reduced if they were a part of a community project splitting them rather than if they were investing in a single standalone household system.

Under these circumstances cost may become less of a barrier making it more feasible to establish RET systems supported by Li-ion batteries. Furthermore the Li-ion battery market is expected to grow rapidly in the coming years, and is expected to overtake the demand for other battery types (Diouf & Pode 2015). This growth is not however being driven by demand from the RET market, despite the potential to become the biggest market for demand, but rather from the consumer electronics and automotive markets (Diouf & Pode 2015). It is because of the expected growth in these areas that the cost of Li-ion batteries is estimated to fall approximately 50.0% by 2020 compared to 2009 prices (Diouf & Pode 2015).

Cost is the most significant factor when it comes to the penetration of Li-ion batteries for use in decentralised energy storage. Reduced costs would significantly increase their uptake which in turn would mitigate some of the negative impacts associated with the setup of RETs projects, and avoid the impacts of using alternative means of energy storage.

7.5. Summary

The feasibility of implementing any RET project for decentralised modern energy generation relies on being able to store sufficient levels of energy to be able to satisfy demand. The use of chemical storage systems were identified as the most practical means of overcoming the issues of intermittent or off peak energy production, but were also found to contribute significant environmental impacts to any final project.

The repurposing of EOL Li-ion batteries from the automotive industry appears to offer a feasible option for energy storage which also helps mitigate many of the impacts associated with battery production, especially GWP, as these impacts may have been partially or completely offset during the use phase of the batteries first life.

The mass of battery required to be able to store the required level of energy to meet demand is determined by the batteries energy density and the level of demand. Batteries with high energy densities are preferred as they reduce the mass of battery required, thus reducing the associated impacts.

The energy demand of India’s rural communities was found to vary considerably dependent upon the scope of the population being assessed. The results highlight that energy demand has to be explored on a case by case basis to ensure the correct level of demand is ascertained. A potential way of dealing with this is via the use of energy forecasting techniques, which will be explored in the next chapter.

Chapter 8. The Impacts Of Changing Primary Energy Consumption In Rural Indian Communities, Through The Application Of Rets

8.1. Introduction

In the previous chapter the potential environmental impacts which can be associated with a decentralised Renewable Energy Technology (RETs) system as a result of the manufacture of standalone energy storage systems was explored. These impacts could potential result in the carbon saving made through the use of RETs being negatively offset prolonging the period before an RET system starts making a positive impact on carbon mitigation in comparison to traditional means of energy generation.

The desire for improved energy security and the mitigation of the impacts caused by greenhouse gas (GHG) emissions are two factors that are helping drive the uptake of RETs (Bull 2001, Martinot *et al.* 2002). The public and political pressures' resulting from these factors is prompting governments and NGOs to support their expanded use.

In order to be able to implement policies that can be used to help overcome the barriers to the expanded use of RETs, governments and NGOs need to accurately model energy demand which is an essential component in effective policy design (Bhattacharyya & Timilsina 2010).

Energy modelling is also an important approach as it allows the impacts of varying energy demand and provision to be quantified and predicted. For example changes in primary energy consumption and GHG emissions can be forecasted.

Several studies have explored the impacts of varying energy demand and provision within developing countries through various methodologies.

Daioglou *et al.* (2012) used a bottom up energy model of urban and rural households in five developing countries to explore the impacts of introducing policies aimed at reducing GHG emissions by imposing a carbon tax on commercial fuels (Daioglou *et al.* 2012). The model used a set of parameters to determine energy demand for several end-use functions e.g. cooking, lighting, and space heating. The model showed that although the tax led to a reduction in carbon emissions from residential energy use, it caused an unwanted side effect of slowing or even reversing energy transition, by forcing poorer households to use traditional fuel sources (Daioglou *et al.* 2012).

Silva Herran & Nakata (2012) developed a linear programming model to improve the design of decentralised electrical energy systems, which utilised biomass resources in rural communities of developing countries (Silva Herran & Nakata 2012). Their model evaluated potential systems based on their financial viability and mitigation of CO_2 emissions. They found that despite the reduced conversion efficiency of biomass fuels, a reduction in CO_2 emissions was observed. Although an increase was seen in unit costs, the reduced supply costs resulted in higher net incomes for households (Silva Herran & Nakata 2012).

In addition, LEAP (Long-range Energy Alternatives Planning system) is a widely used tool for energy policy analysis and climate change mitigation assessment (Ahanchian & Biona 2014, Bautista 2012, Heaps 2012, McPherson & Karney 2014, Mustonen 2010, Özer *et al.* 2013, Park *et al.* 2013, Shin *et al.* 2005, Suganthi & Samuel 2012). It can be used to analyse the supply of energy and the resulting GHG emissions at both local and national levels (Bhattacharyya & Timilsina 2010, Heaps 2012, Park *et al.* 2013, Suganthi & Samuel 2012). The software can also be used to interpolate data for a range of factors including population growth, energy demand and changes in energy feedstocks.

Park *et al.* (2013) used the modelling tool LEAP to build a bottom up energy model exploring the impacts three scenarios of electricity generation in South Koreas would have on primary fuel consumption and GHG emissions (Park *et al.* 2013). LEAP was also used by Özer *et al*. (2013) to analyse how the introduction of new policies aimed at increasing the use of RETs in Turkey's energy mix would impact upon CO_2 emissions in comparison to the countries current strategies (Özer *et al.* 2013). This model accounted for the predicted growth in energy demand and the resulting CO_2 emissions from primary energy sources over a 24 year period (Özer *et al.* 2013).

LEAP has also been used to model how the introduction of modern forms of energy under different stimulus policies affected total energy demand and fuel consumption in Laos' rural communities by Mustonen (2010). This study highlighted how the introduction of modern energy sources under optimal conditions can result in the displacement of more traditional fuels such as firewood and kerosene and increase end-energy consumption (Mustonen 2010).

LEAP has been used to model energy use and GHG emissions in India and the effects varying policy scenarios have on these, including the introduction of RETs (Kadian *et* *al.* 2007, Kale & Pohekar 2014). None of these studies however have specifically focused on rural communities. Studies have modelled rural energy usage in India without LEAP (Castellanos *et al.* 2015, Urban *et al.* 2009). These studies have focused on individual villages or a specific subset of rural villages rather than exploring the wider implications of using decentralised RETs in all rural households at a national level.

8.2. Aims & Methods

This chapter aims to address the objective of determining the wider environmental impacts which may result from the use of RETs as a means of delivering decentralised energy in the rural communities of India.

The integrated energy modelling tool LEAP was utilised to achieve this aim by modelling household energy use in rural India to highlight the long term environmental benefits of substituting current means of energy provision with decentralised RETs. Furthermore the beneficial effects of using RETs on national total energy demand and primary fuel consumption were also be explored.

The materials and methods undertaken in the completion of the energy forecast modelling completed in this chapter can be found in Chapter 3.3.

As with any modelling there are a range of limitations and caveats which must be taken into consideration when evaluating the results.

The first to consider is that each model uses a different set of parameters around which they are built. Each model has a different household population and baseline per capita levels of energy demand and fuel consumption. These models were calculated by using the per capita energy consumption models developed in Chapter 7 and the standard Indian household models from Chapter 4.2.7 and Chapter 5.3.7, which are based on the average values from the surveys conducted in those studies.

In addition the levels of fuel consumption used for the average rural household used in Model 1 were extrapolated using the national per capita energy consumption described by Khandker *et al* (2010) and the ratio between fuels consumed by the average household used in the Model 2. The link between these models has been used to explain the similarities observed in some of the modelling results.

A conservative estimate of 50.0% was used to represent the number of households which would replace their current fuels for RETs under each of the scenarios. Higher or lower percentages could have been applied which would have altered the final results.

The models do not take into account factors such as population growth, urbanisation or financial restriction. It is assumed that population remains constant and that the households have the financial capabilities to meet the expect growth in energy demand as well as any additional costs of using RETs. They also do not take into account any additions or losses that may occur in the composition of the existing national electricity generation mix.

A uniform increase is also assumed across all areas of household energy demand. In actuality the growth in demand may be seen to a greater extent in some areas. It is also possible that the demand for energy for some activities would reach an upper limit beyond which there would be no additional energy demand.

8.3. Results & Discussion

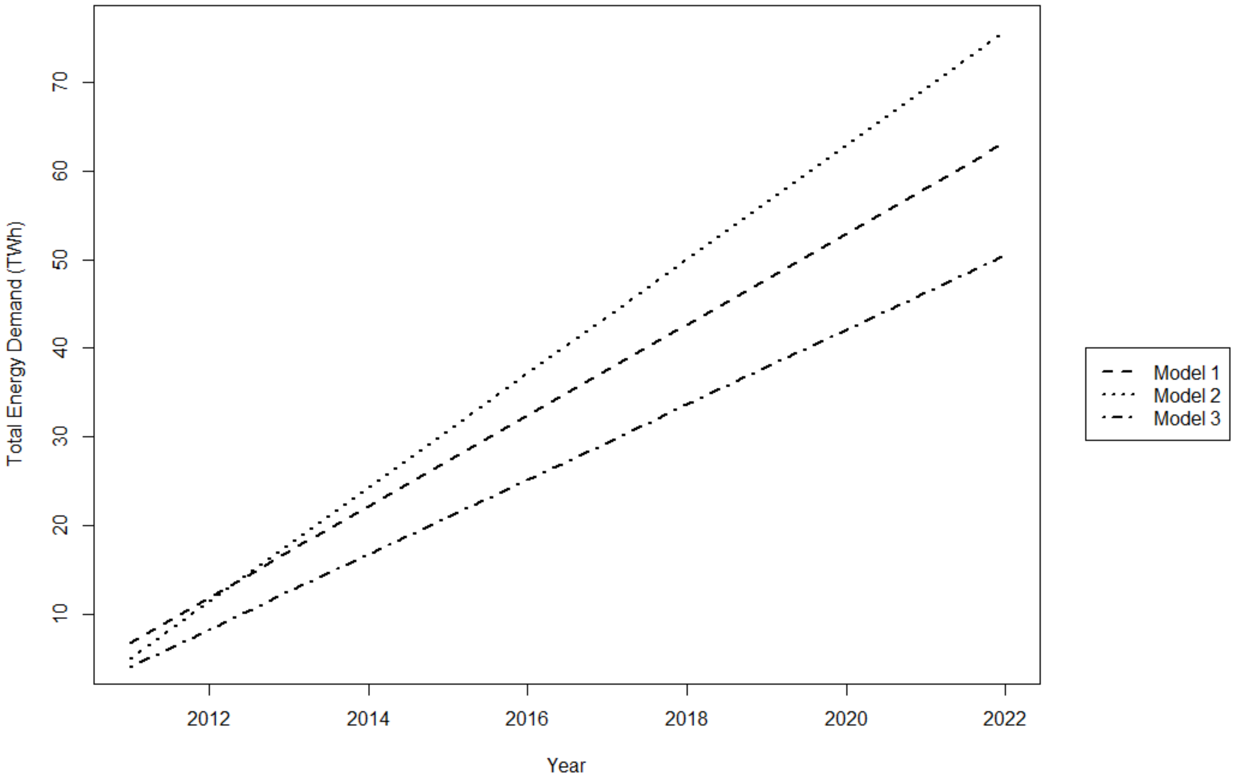
8.3.1. Changes In Total Energy Demand

Figures 8.1 and 8.2 show the variation observed in total energy demand between the different models and the scenarios of current fuels replacement with RET as outlined in Table 3.3. The raw data is presented in Appendix 5.

The starting total energy demand of each model is different, 6.77 TWh under Model 1, 4.99 TWh under Model 2 and 4.02 TWh under Model 3. However by the end year total energy demand under Model 2 is the highest of the three models, followed by Model 1 and the lowest total demand being observed under Model 3 (Figure 8.1).

The rate at which total energy demand increases varies between the three baseline models. The rates of increase were 5.13 TWh/year in Model 1, 6.44 TWh/year in Model 2 and 4.23 TWh/year for Model 3.

Figure 8.1: Comparison of growth in total energy demand of rural India's household under baseline scenario.



The differences in the start and end year levels of total energy demand observed in the baseline scenarios of the models can be explained by looking at the parameters that were applied in each (Tables 3.4 – 3.6). The number of households is the same for each model; however between each model the number of occupants per household, the starting per capita energy demand and therefore the total energy demand is different.

Under the baseline scenario, in the start year the model with the highest per capita energy demand (Model 1) also has the highest total energy demand despite having a smaller household population size compared to Model 2. However, as the per capita energy demand increases in the model to meet the end year target, household size becomes a much more important factor.

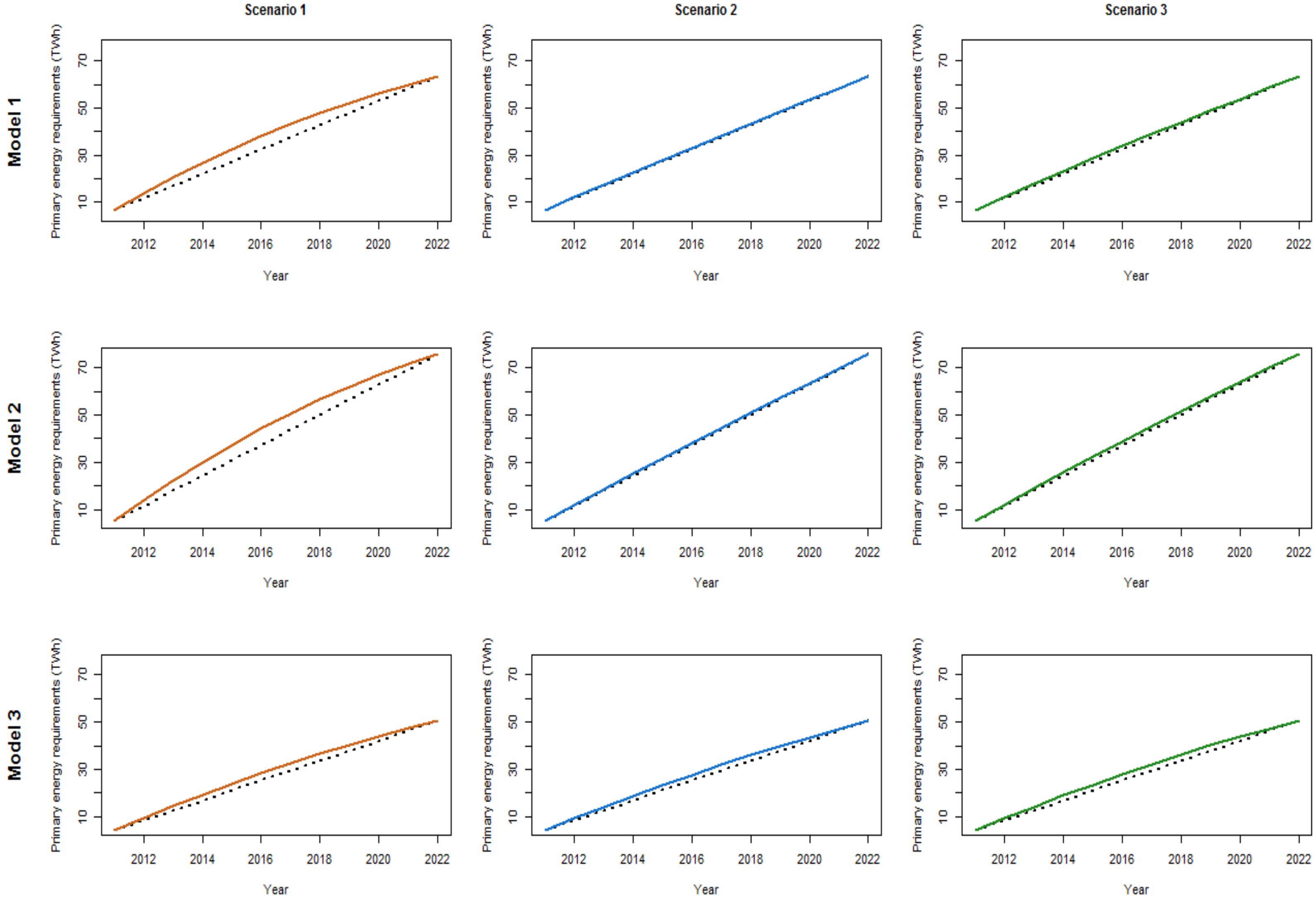
Model 2 which is based on the findings of Chapter 5, with its higher number of occupants overtakes Model 1 in terms of total energy demand. It becomes very apparent that household size is a crucial factor and has a substantial effect upon total energy demand. Despite only a small change per household, this increase is substantial when applied across the entire rural population and causes the rate by which energy demand grows to be higher in the models with the higher household populations.

Households in Model 3, which is based on the results of Chapter 4, have the smallest population and per capita energy demand which explains why this model has the lowest total energy demand in the start year. Having the smallest household size also means that as the per capita energy demand increases the rate by which total energy demand increases is much slower than compared to Model 1 and 2.

These results shows that even small changes in the basic parameters applied in a model can have a significant effect on the findings from it. This could lead to inaccurate conclusions being drawn, such as over or under estimating the level of demand, which could result in inadequate action being taken or inappropriate policies being designed.

This is seen with household size, which is seen to be an important factor in determining total energy demand. Both Models 2 and 3, which are based on the data collected in Chapters 4 and 5, have different average household sizes compared to that outlined in the 2001 Indian census (ORGC India 2001a) which ultimately affects their total energy demand.

Figure 8.2: Variation in total energy demand caused by decentralised RETs substituting current fuels under differing replacement scenarios compared to demand growth of baseline models (dotted line).



The introduction of RETs to replace fuels currently used for household activities causes the total energy demand to increase at a faster rate compared to the baseline scenario (Figure 8.2) under all the all the scenarios (Table 3.3) for each model (Table 3.2). This is because the introduction of RETs allows each household to immediately increase their energy consumption for the activity being supplemented by RETs to the end year value rather than the steady year on year increase that is seen in the baseline scenario. It is reasonable to assume this as the household would not steadily increase their use of the RET but rather use it to its full potential.

In these instances total energy demand increases relative to the specific fuel which is being replaced. The larger a fuels contribution to total energy demand, the higher the level of increase. Rates of increase are higher under Scenario 1 than Scenarios 2 and 3 in all of the models, as the fuels used for cooking represent a larger portion of total energy demand. So when RETs replace them the increase in energy demand is greater.

This increase was less pronounced in Scenario 1 of Model 3 as the contribution of cooking fuels to total energy demand in this model was smaller. Additionally the increase in demand observed under Scenarios 2 and 3 of Model 3 is at a higher rate than that observed in these scenarios under Models 1 and 2. This is because the contribution made by the fuels being replaced in Model 3 to total energy demand was higher than in Models 1 and 2. Although the contribution is higher under these scenarios in comparison to Models 1 and 2, the actually total energy demand is still smaller.

Changes in the contribution different fuels made to the total household energy demand altered the rate of total energy demand growth, thus the curvature of the scenario lines. Using RETs to replace fuels which make a larger contribution to total household energy demand can help speed up the transition to higher per capita energy provision.

8.3.2. Primary Energy Consumption

Figure 8.3 shows the changes in primary energy consumption which occurs between the start and end year of the modelling period, as the level of demand increases and as decentralised RETs are introduced to replace certain fuels. A full chart showing the changes in contribution made by different fuels over time is presented in Appendix 6.

The levels of primary energy consumption increase in direct correlation with the growth in energy demand simply because more fuel is needed in order to satisfy this demand. However the contribution individual fuels make to total primary energy consumption can and does change over the 11 year model period depending upon the scenario which are being explored.

Under the baseline scenario of each model the contribution each fuel makes to primary energy consumption remains constant as it assumed that as energy demand increases the extent by which fuels are consumed will also increase relative to their contribution made in the start year.

The baseline energy mixes of each model are however different. This is because of the differences in the parameters used in each model for the amount of each fuel consumed for certain tasks. As the scenarios for each model changes the expanded use of RETs causes the displacement of other fuels. This changes the composition of the energy mix thus the contributions individual fuels make to the total primary energy requirements compared to the baseline.

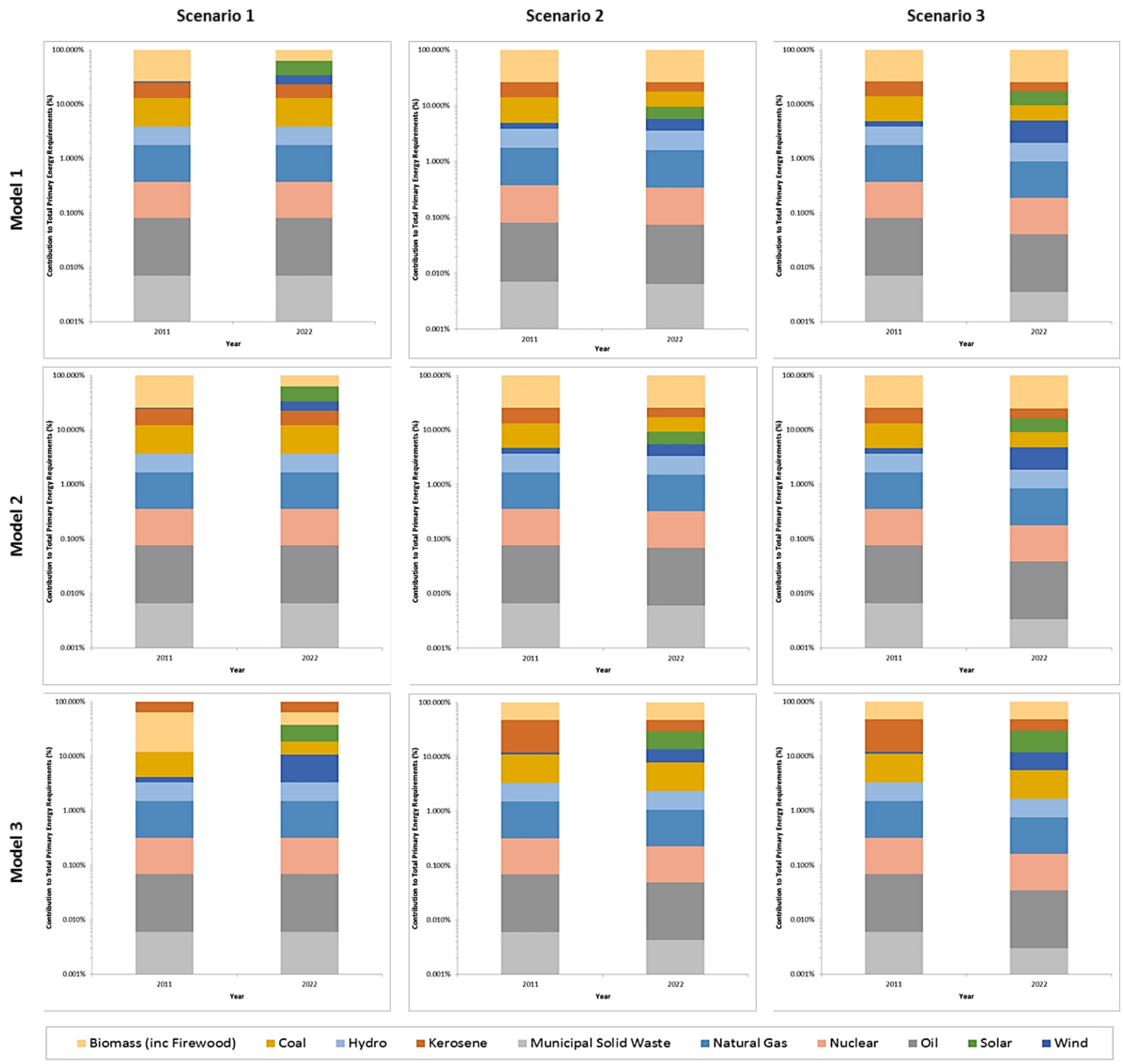
The contribution different fuels make to the energy mixes of Model 1 and 2 are very similar. This is because the values applied to Model 1 through the parameters for fuel consumption were extrapolated by using the ratios of fuel use in Model 2.

This relationship helps explain many of the similarities between Model 1 and 2. Although levels of energy demand and total primary fuel consumption are different in these two models, many of the changes observed under the different scenarios applied to them occur at the same ratio. In particular the change in the contribution different fuels makes to total energy requirements and the change in the volume of fuels consumed.

Under the different scenarios despite the volume of fuels consumed all increasing in line with the growth in energy demand, the contribution the different fuels make changes depending upon the fuels which are being replaced by the use of RETs for specific activities.

In Models 1 and 2, Scenario 1 causes a notable drop in the contribution made by biomass fuels to total energy requirements between the start and end year, from 73.6% to 36.9% in Model 1, and from 74.2% to 37.22% in Model 2. This is because in these models biomass is the primary fuel source used for cooking. Therefore its share falls as it is replaced by decentralised RETs. The contribution of kerosene is also seen to fall as it too is replaced by decentralised RETs but by a smaller amount as its use is expanded for household lighting.

Figure 8.3: Changes between start and end year of primary energy consumption needed to meet total rural household energy demand resulting from the introduction of decentralised RETs under varying fuel substitution scenarios compared to baseline models.



A drop in the contribution made by biomass to total energy requirements is also observed in Model 3 under Scenario 1, from 52.0% to 26.1%. Its contribution in the start year is however already smaller than in the other two models. However unlike in Models 1 and 2 no decrease is seen in contribution that any other fuel makes as biomass is the sole fuel being replaced.

In all of the models the share biomass makes drops by approximately 50.0%, from the start year to the end year, reflecting the assumption that half of all household had their cooking fuel replaced by the end year under Scenario 1. Despite this drop, in the end year of Models 1 and 2, biomass remains the top most widely used energy source. However in Model 3 the contribution of kerosene has increased steadily each year, overtaking biomass in 2018 to become the highest contributing energy source, reaching 36.0% by the end year.

With the exception of Scenario 1 of Model 3, biomass consistently accounts for the largest contribution to primary energy requirements across the entire modelling period under all model and scenarios.

Scenario 2 and 3 when applied in each of the models causes the contribution made by the fuels used to generate centralised electricity to primary energy consumption to decrease over the modelling period. In each of the models this includes the contributions from hydro, nuclear, oil, natural gas, coal and municipal solid waste.

Despite the expanded use of kerosene as a fuel for cooking, as a larger portion is being displaced by decentralised RETs in Models 1 and 2, under Scenarios 2 and 3, its total contribution to primary energy requirements decreases. Furthermore as kerosene constitutes a larger portion of the energy being replaced in both Scenario 2 and 3 the degree by which is contribution falls is greater than any of the other fuels.

A similar pattern is seen in Model 3 under Scenario 2 and 3, however as kerosene is not used in cooking the degree and rate by which its total contribution falls is faster and further in both of these scenarios. From 36.0% to 18.1% in Scenario 2, and to 18.2% in Scenario 3.

Under Scenario 3 the contribution that the fuels used in centralised electricity generation make to total primary energy consumption decreases further and at a faster rate than compared to that observed under Scenario 2. This is simply explained as in Scenario 3 all of the energy used for the ‘other appliances’ is electricity drawn from the grid. Therefore its replacement reduces the demand on centralised electricity generation thus the consumption of fuels for its generation. This pattern is seen across all the three models.

In all of the scenarios applied to each of the models the contribution solar and wind energy make to total primary energy consumption is observed to increase. This is because these are the RETs used to replace the fuels under the different scenarios. Solar energy sees the largest and faster rate of increase in all of the models as it is the primary RET used to meet the change in energy demand.

For example under Scenario 1 of Model 1 the contribution of solar and wind energy is seen to grow year on year making up 29.1% and 10.5% of total energy requirements respectively by the end year. Similarly by the end year of Scenario 1 of Model 2, the contributions of Solar and wind energy have increased from 0.05% to 29.4% and 1.0% to 10.9% respectively.

Under Scenario 1 of Model 3 the contribution from solar energy increases from 0.05% to 19.4% by the end year and wind energy's from 0.9% to 7.4%. Under Scenario 3 the contribution of solar energy increases from 0.05% to 17.4% by the end year and wind energy increases from 0.9% to 6.3% by the end year.

The degree by which these RETs are used depends upon the fuels they are displacing. For example in Scenario 2 of Model 1 the contribution wind and solar make to total primary energy consumption increases from 1.09% to 6.02% between the start and end year. Whereas in Scenario 2 of Model 3 their contribution increases from 0.93% in the start year, to 21.71% in the end year. This is because the energy demand for lighting in Model 3 is higher than in Model 1 and means that the fuels used for lighting in Model 3 make a larger contribution to total energy requirements than those used in Model 1. Therefore as they are displaced over the 11 year model period by the introduction of decentralised RETs, the level of contribution shifts from the one energy source to the other.

It is the gradual introduction of decentralised RETs which causes the displacement of the other fuels and causes the changes in the contributions different fuels make to total primary energy consumption observed over the 11 year model. Unsurprisingly the changes in primary energy requirements in each model reflect the fuels which are being replaced by RETs under the scenario that is being applied to the baseline model. Across all the scenarios of each separate model the contribution the fuels being replaced by decentralised RETs decreases and the contribution of the decentralised RETs (solar, wind) being used to replace them increases.

However despite the increases observed in the contributions made by decentralised RETs, separately they never become the dominate fuel source. However, under Scenario 1 in Models 1 and 2, their combined contribution to primary energy consumption makes them the dominant source of energy.

In addition to the environmental benefits of using RETs, their expanded use has also been shown to improve energy security by diversifying the countries energy mix and by reducing dependency on unsustainable or imported energy sources such as oil and coal (Bull 2001, Karytsas & Theodoropoulou 2014, Martinot *et al.* 2002).

Energy forecast modelling using LEAP not only aids in identifying fuels which contribute large levels of GHG emissions, but also in targeting the replacement of fuels which pose a risk to energy security. Changing the composition of the fuels used to meet household energy demand through the expanded use of RETs improves energy security not only at a national level but also for individual households (Escribano Francés *et al.* 2013, Wang *et al.* 2014a). This is because as these energy sources are essentially an indigenous energy source they are less susceptible to outside influences in particular price shocks (Ölz *et al.* 2007).

8.3.3. Contribution To Global Warming

Figure 8.4 and 8.5 show the changes in the levels of CO_2e* emitted between the baseline for each model and when decentralised RETs are introduced to replace current fuels under the three scenarios outlined in Table 3.3. The raw data is presented in Appendix 5.

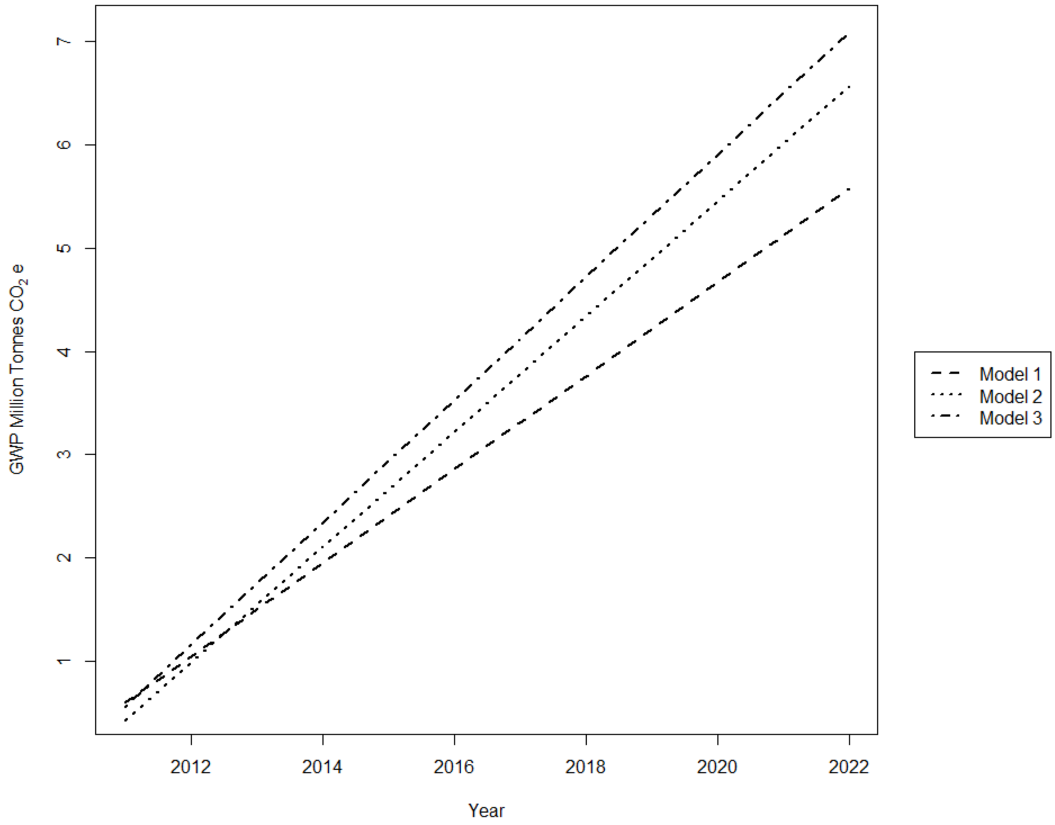
As energy demand increases as does the contribution made to global warming through GHGs emissions. This is because in order to meet this growth in demand the amount of fuel being consumed must also increase.

As observed with energy demand, the levels of CO_2e emitted during the start year of the baseline scenarios of each model all differ (Figure 8.4). With Model 1 having the highest GWP value (0.60 million tCO_2e) across all the baseline scenarios followed by Model 3 (0.56 million tCO_2e) and then Model 2 with the lowest GWP of 0.43 million tCO_2e. This is a result of the different volumes of fuels being consumed as well as the different types of fuels consumed to meet household energy demand.

However by the end year of the baseline scenario, the GWP of Model 2 increased to 6.57 million tCO_2e. Model 1 had the lowest GWP (5.57 million tCO_2e) and Model 3 the highest (7.09 million tCO_2e).

* CO_2 equivalent

Figure 8.4: Comparison of growth in global warming contribution of rural India's household under baseline scenario



The rate at which GWP increased per year under the baseline scenario of Model 3 was higher than the other two models as indicated by the per year rates of GWP increase. The rate of increase for Model 1 was 0.45 million tCO_2e per year, 0.56 million tCO_2e per year for Model 2 and 0.59 million tCO_2e per year for Model 3.

The types of fuels used were the main factor which affected the levels of CO_2e emitted. Fuels that are associated with high levels of CO_2e emissions and make a high contribution to total energy requirements cause the rate at which CO_2e emission increase to be higher.

This is most apparent in the baseline scenario for Model 3, which despite in the end year having the lowest total energy demand has the highest CO_2e emissions. In contrast the baseline scenario of Model 1 shows that despite having the highest energy demand and CO_2e emissions in the start year, by the end year it is associated with the lowest level CO_2e emissions despite having the second highest total energy demand.

The main difference between these two models is the volume of kerosene consumed. In Model 3, 130.0% more kerosene is consumed than in Model 1 just in the end year, this results in an additional 2.79 million tCO_2e being emitted in the end year alone.

Kerosene has not only been associated high levels of GHG emission but has also been shown to be linked to several negative health impacts (Epstein *et al.* 2013, Lam *et al.* 2012, WHO 2009). Therefore its replacement with RETs could also result in more direct benefits for rural households beyond the benefits of climate change mitigation.

In the baseline scenario of Model 2 total CO_2e emissions rise sharply from the lowest of the three models in the start year, to the second highest by the end year. The composition of primary energy consumption in Model 2 is very similar to Model 1 as discussed previously. Despite having similarly energy mixes the household population size of Model 2 causes the rate by which GHG emission increases to be higher and the total CO_2e emitted in the end year to be higher than Model 1.

Although household size does have an impact of total CO_2e emission because it affects the total household energy demand and therefore the rate by which total GHG emissions increases by. It is primarily the types of fuels and the extent by which they are used which has the greatest impact on total GHG emissions. This is further highlighted by the effect the different scenarios have when applied to each model.

Each scenario explores how the replacement of the fuels used to accomplish certain household tasks with RETs impacts on total CO_2e emissions. Replacement of high GHG emitting fuels causes the highest reduction in CO_2e emissions.

As shown in Figure 8.5, under Model 1 the use of decentralised RETs to replace the fuels currently used for cooking (Scenario 1) resulted in a reduction of 1.02 million tCO_2e being emitted compared to the baseline scenario in the end year, and provided a total saving of 4.45 million tCO_2e across the 11 years. When the fuels used for lighting are replaced with decentralised RETs (Scenario 2) the end year contribution to global warming is 0.87 million tCO_2e less than the baseline and equals 3.80 million tCO_2e being avoided across the entire model. When the energy sources used for other appliances are replaced along with lighting (Scenario 3) the end year CO_2e emission are 1.77 million tonnes less than the baseline and results in a total avoidance of 7.74 million tCO_2e.

The results for Model 2 (Figure 8.5) showed that under Scenario 1 the end year tCO_2e emissions are 1.23 million tonnes less than the baseline scenario, and results in a total saving of 5.29 million tCO_2e across the entire model. When decentralised RETs were used to replace the fuels used for lighting (Scenario 2) the contribution to global warming in the end year is 1.05 million tCO_2e less than the baseline and equals 4.52

million tCO_2e being avoided across the entire model. Under Scenario 3 the end year CO_2e emissions are 2.05 million tonnes less than the baseline and equates to a total of 8.83 million tCO_2e being avoided.

The GWP results for Model 3 shown in Figure 8.5 indicate that using decentralised RETs under Scenario 1 resulted in 0.36 million tCO_2e being emitted less than the baseline scenario in the end year, and a total saving of 1.57 million tCO_2e across the entire model. Under Scenario 2 the end year contribution to global warming was 2.88 million tCO_2e less than the baseline and equates to 12.44 million tCO_2e avoided across the entire modelling period. When Scenario 3 is applied to Model 3 a reduction of 3.18 million tonnes is seen in the end year CO_2e emission compared to the baseline. This scenario also leads to a total of 13.77 million tonnes of CO_2e being avoided compared to the baseline.

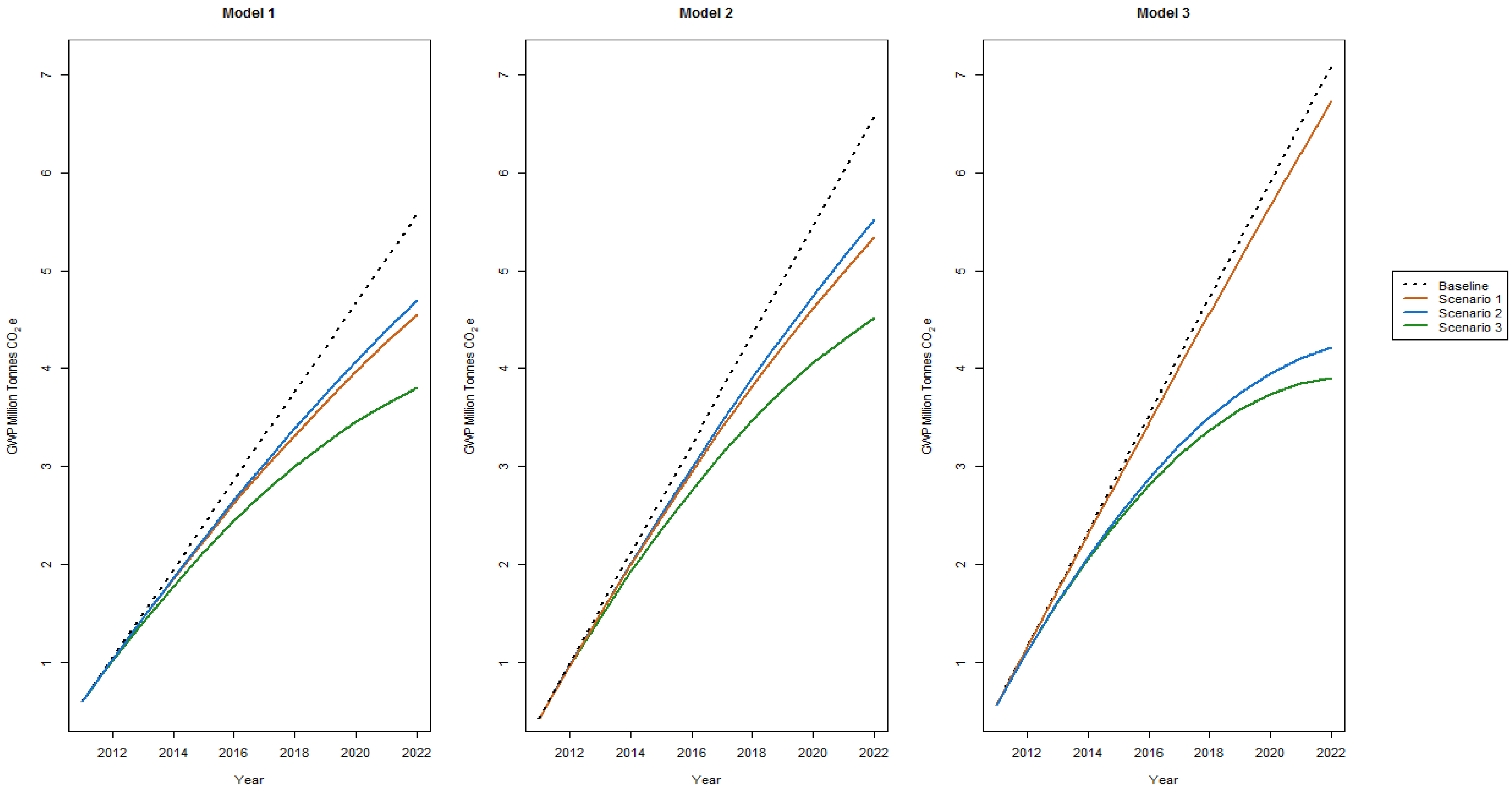
The effects of each of the different scenarios in Models 1 and 2 are similar. Again this is because of the similarities between the compositions of the fuels used to meet primary energy requirements in these two models and results in similar volumes of CO_2e being avoided in each of the different scenarios in comparison to their respective baseline.

In both models the replacement of fuels used for cooking (Scenario 1) resulted in a larger reduction in CO_2e emissions than those used for lighting (Scenario 2). Indicating that the volume and type of fuels used for cooking are associated with a higher proportion of GHG emissions. This relationship is not however seen in Model 3, where Scenario 1 results in a very small reduction in CO_2e emissions compared to the baseline, but the replacement of the fuels used for lighting (Scenario 2) resulted in a larger saving.

This difference between the models is likely due to the quantities of kerosene used for each task. Kerosene is used for cooking in Model 1 and 2 but not in Model 3 and although it is used for lighting under all three models it is used far more extensively in Model 3 compared to the other two, and makes a larger contribution to total energy requirements.

As describe previously kerosene is associated with high levels of GHG emissions, thus its replacement would result in the avoidance of these emissions. The differences in the levels of kerosene replaced would explain the variation in the curvature of the lines for each scenario under each model. Where a large quantity of kerosene is being replaced as seen in seen in Scenario 2 of Model 3, the curve is more pronounced as a larger portion

Figure 8.5: Changes in global warming contribution resulting from decentralised RET substitution of current fuels under differing replacement scenarios compared to baseline models.



of total GHG emission is being avoided. When a smaller amount is being replaced the levels of CO_2e avoided are also smaller which results in a more gradual curve.

The potential of using RETs to replace multiple household activities is explored through Scenario 3. The combined replacement of fuels used for lighting and other appliances was selected as doing so would remove the need entirely for grid connectivity, and thus would avoid the GHG emissions which result from centralised electricity generation.

In all of the models it is this scenario which resulted in the largest total volume of CO_2e being avoided across the 11 year period. Under models 1 and 2 the volume of GHG emissions avoided is almost evenly split between the two activities. Under Model 3 however the majority of the GHG saving comes from the change in the energy source used for lighting. There may also be additional benefits as removing the need for centralised grid connectivity also removes the need for infrastructure which has been highlighted as significant barrier to modern energy access and can also result in deforestation and habitat destruction (Mitchell *et al.* 2011, Painuly 2001).

As seen in the baseline scenarios it is not only the contribution that different fuels make to total energy demand but also the relative associated level of CO_2e emissions which change the total levels of CO_2e emitted and avoided.

The use of RETs to replace fuels can clearly have a substantial impact upon reducing total CO_2e emissions. The extent of this can be amplified by targeting fuels which are associated with contributing the largest concentration of CO_2e to total emissions. This may not always be the fuel which makes the largest contribution to total energy demand, as seen in Model 3, where biomass makes the largest contribution to total energy but kerosene results in the largest contribution to total GHG emissions. The replacement of biomass (Scenario 1) resulted in a smaller total volume of CO_2e being avoided over the 11 year model period than observed in Scenario 2 where kerosene is replaced.

Based on the findings of each model, if RETs were used to replace the fuels for a single activity, cooking would be the recommended activity based on Model 1 and 2, but lighting based on Model 3. Differences in the parameters applied to these models leads to different conclusions being drawn, which as highlighted when discussing total energy demand, may result in inaccurate assumptions being made, leading to inappropriate policies being designed.

A better approach may be to assess the contribution individual fuels make to total GHG emissions and target their replacement. This may lead to the replacement of fuels used in multiple activities, as seen under Scenario 3, but will ultimately result in higher volume of CO_2e being avoided.

8.4. Summary

The integrated energy modelling tool LEAP was used to model the energy use of rural India's households and the effects of using decentralised RETs to replace the fuels currently utilised.

GHG emissions increased in line with growth in energy demand. It was primarily the types of fuels and the extent by which they were used which had the greatest impact on total GHG emissions. The use of RETs can lead to a substantial reduction in the total CO_2e emissions; however the extent of these reductions is dependent on the fuels they are replacing. The targeting of specific fuels rather than activities may lead to higher volumes of CO_2e being avoided.

The introduction of RETs causes the rate by which total energy demand increases to be higher after replacement, as it allows a faster transition to higher per capita energy provision. As with GHG emissions this increase is dependent upon the fuels being replaced, with fuels that represent a larger proportion of total energy demand resulting in a higher level of increase.

Although the volume of each individual fuel consumed increases with the growth in total energy demand, the contributions these fuels made to total national primary energy requirements differed. As RETs were introduced they caused the displacement of fuels, reducing their contribution to total primary fuel consumption, which ultimately could improve energy security both at a national and household level by diversifying the countries energy mix.

The results showed that even small changes in the parameters applied to the models could have a significant effect. The most important factors identified were household population size, the types of fuels used as well as the extent by which they were used, as these were shown to play a crucial role in determining the volume of GHGs avoided, along with the rate by which energy demand increased and the changes observed in the composition of primary energy consumption as a result of RET replacement.

Chapter 9. General Discussion & Recommendation

The work conducted in this thesis aimed to explore the potential of delivering modern energy services through low carbon technologies to rural and remote communities in developing countries and the impacts and barriers associated with their use.

9.1. Available Renewable Energy Technologies

This thesis started out by exploring the need for modern energy access and the importance of low carbon energy sources.

Assessment of the different technologies which were available and suitable for decentralised applications (Chapter 2.1.2) indicated that solar and wind technologies are the most viable options for delivering sustainable modern energy to the rural and remote communities of developing countries, despite the high investment costs per kW produced (IEA 2007). Solar technologies were highlighted as having substantial potential in India because of the wide spread high levels of solar irradiance the country receives annually (MNRE 2009, SolarGIS 2014).

Both can avoid additional costs which can result from the need to purchase land for installation as they can be installed directly onto buildings or roof tops. In addition untapped land resources such as brown field sites or contaminated land can be made useful by being selected as installation sites, thus avoiding the loss of useful land (El Bassam & Maegaard 2004, Hernandez *et al.* 2014). However it must be noted that the site specific nature of the technologies may mean that they are not the most suitable technologies in all areas, and that the direct impacts will be dependent upon local conditions (Ehnberg & Bollen 2005, Nugent & Sovacool 2014).

The findings of rural energy surveys conducted and presented in Chapter 4 and 5 established that there is substantial potential for the use of RETs in rural India. Every respondent across both of the surveys conducted, totalling over 100 respondents, indicated using at least one traditional primary energy source (firewood, biomass) for either household cooking or lighting. This means that none of the households surveyed during these studies meet the criteria for modern energy access set out by the UN Advisory Group on Energy and Climate Change (UN-AGECC). They are not even meeting the criteria to meet the UN-AGECCs definition of energy for ‘basic human needs’ (UN-AGECC 2010).

This thesis has suggested that the application of decentralised RETs could be used to displace the use of these fuels, thus raising the energy access level these households meet. The use of more efficient modern energy sources will also enable better use of time which could allow for additional income generation thus further improving living conditions.

9.2. Barriers To Application Of RETs

The findings of the rural energy surveys presented in Chapters 4, 5 and 6 identified several key barriers to the application of RETs as a means of delivering decentralised modern energy services in rural India. Some of these barriers were highlighted more often and by multiple respondents. These barriers included cost, reliability as well as awareness and understating of RETs.

9.2.1. Cost

Cost was shown through the results of the surveying conducted in this thesis (Chapter 4 and 5) to be an important limiting factor when it came to fuel selection. The pattern of fuel use observed in the results of the survey conducted in Maharashtra (Chapter 4) even suggested that respondents were sacrificing ease of use in favour of cheaper fuels. Given that the high costs associated with the installation and maintenance of many RETs have already been identified as a major barrier to their uptake (Dombi *et al.* 2014, Painuly 2001, Reddy & Painuly 2004), this work has further highlighted the key consideration needed to be given cost to ensure the poorer communities are not marginalised and to ensure the viability of RET projects by not restricting access. This should be done through the implementation of policies which provide incentives or grants to cover the cost of these projects or support their on-going use. The incentives for governments to do this come from the benefits modern energy provision via RETs offers. In particular the facilitation of local development, improve health and increased energy security.

However, as identified by Mitchell *et al.* (2011), a lack of knowledge and experience in designing and implementing such policies can result in their failure. It may be necessary and prudent to seek assistance from other agencies or governments with prior experience to ensure the design and of successful and effective policies.

The survey work completed in this thesis (Chapters 4 and 6) also indicated the underlying themes influencing respondents' attitudes towards RETs, which included financial constraints. These constraints did not solely centre on poverty, but instead were also widely associated with financial flexibility. Households with little or no flexibility in their budgets were restricted to the fuels they used and were less in favour of RETs because of concerns surrounding affordability. Cost is recognised as a major barrier to the uptake of RETs, (Painuly 2001, Reddy & Painuly 2004) thus identifying people with this concern could enable appropriate action to be taken to surmount this barrier.

9.2.2. Reliability

Although cost is likely to be the most important factor affecting uptake, reliability was also highlighted to be a significant barrier to the long term viability through the findings of the rural energy surveys presented in Chapter 4 and 5. Del Río (2007) and Painuly (2001) outlined how long term viability of RET projects could be threatened by a lack of technical experience in their set-up and operation, which could lead to performance and reliability issues, both of these factors were concerns highlighted by respondents in both surveys (Chapters 4 and 5). Poor performance and reliability issues can not only result in a projects failure but can further exacerbate the barriers to the uptake of RETs by damaging their perception (Moomow *et al.* 2011, Painuly 2001).

9.2.3. Education, Awareness & Understanding

Despite there being an initial lack of fundamental knowledge and understanding of RETs, the findings of the rural energy surveys of Orissa and Maharashtra completed in Chapters 4 and 5 showed that many respondents identified examples but were unaware that they were considered RETs. Once provided with an overview, substantial interest was shown in their use over current means of energy generation. This highlights the importance of education programs and the impact that they can have on improving acceptance and uptake of RETs. The significance of education has been emphasised by both Jennings (2009) and Kandpal & Broman (2014) as a means of overcoming many of the barriers to the uptake of RETs and their long term viability.

Despite this interest both of the survey studies conducted in this thesis (Chapter 4 and 5) showed that RETs alone offer insufficient incentives to persuade respondents to switch to or contribute towards their set-up. It must be made clear that they offer more than just being renewable sources of energy. Reddy & Painuly (2004) highlighted that the use of RETs is often perceived to be associated with some level of discomfort or sacrifice. It is therefore important that target communities are made aware of the benefits of RETs, and are shown that these energy sources are equal to or better than the fuels they currently use and satisfy their criteria for fuel selection (affordable, reliable and easy to use).

The major underlying factor that connects these barriers is acceptance. It is a factor that is reflected in the results of the rural energy survey studies in Chapter 4 and 5 and has been identified in previous studies (Moomow *et al.* 2011, Painuly 2001). Without acceptance the likelihood of an RET project being successful is reduced, as it is key in order to maintain market viability. Although tackling this broader issue has been discussed in the literature (Cohen *et al.* 2014, Karytsas & Theodoropoulou 2014, Moomow *et al.* 2011) the specific factors which influence it can be varied and specific to certain demographics.

In addition, analysis of the responses from the surveys conducted in this research highlighted a lack of knowledge and understanding as an underlying topic of importance. This lack of knowledge included being entirely unaware of RETs, and/or being miseducated about RETs. Both of these have been identified in the literature as barriers to the uptake of RETs (Del Río 2007, Moomow *et al.* 2011). Those with a lack of knowledge are less accepting and more hesitant about their introduction as they are generally unaware of the benefits they offer. Those who have been miseducated can have misinformed negative opinions of RETs which make them unreceptive to their introduction as they do not perceive there to be any benefits.

9.3. Enabling Renewable Energy Technologies

The need for energy storage systems was identified as not only essential for decentralised energy generation, but also as an area where substantial environmental impacts could originate (Kousksou *et al.* 2014, Nair & Garimella 2010, Yekini Suberu *et al.* 2014). These impacts could contribute to the carbon footprint of an RET project, extending the time before it has a positive offsetting effect on net carbon emissions.

After assessment of the systems available for decentralised energy storage through an extensive survey of existing literature sources, chemical storage systems were identified as the most appropriate and practical option available. A life cycle assessment (LCA) was completed (Chapter 7) to explore the contribution to greenhouse gas (GHG) emissions the production of these batteries can make to the total carbon footprint of a RET system.

The findings of the LCA study presented in Chapter 7.3 indicated that energy density is a vital characteristic as it determines the battery mass required to meet energy demand,

and therefore the volume of different pollutants emitted which can be attributed to an RET project. A smaller storage system may also mean reduced impact at the site of set-up as the installation will have a smaller footprint resulting in less competition for space and habitat destruction.

The results of the LCA study conducted also showed that Li-ion batteries were the best option for energy storage as despite their high GWP per kg of battery mass, their significantly higher energy densities meant a smaller mass of battery was required to meet energy demand. This ultimately means a smaller carbon debt being attributable to any associated RET project.

Repurposed batteries were also explored during Chapter 7, with repurposed Li-ion batteries from hybrid vehicles being identified as suitable candidates for use in renewable energy projects for storage applications. In addition to providing a means of mitigating the impacts of virgin battery production, repurposing of batteries avoids the impacts associated with their disposal and can offer significant economic and environmental benefits through avoiding the need for virgin material extraction and processing of new batteries (Faria *et al.* 2014, Wang *et al.* 2014b).

Assessment of repurposed Li-ion batteries using LCA in Chapter 7.3 showed that despite the degradation in energy density requiring a larger mass of battery to meet energy demand, the emissions attributed to them were still less than some of the other options and similar to virgin Li-ion batteries. Additionally the results of this study showed that when the carbon saving made during the use phase of their first life were taken into consideration these impacts are partially or completely offset. There is also potential for the battery to accumulate a carbon credit which could then carry over to an RET system.

Several studies have outlined the impending challenge that the disposal of end of life Li-ion batteries poses, as the demand for electric and hybrid vehicles grows (Richa *et al.* 2014, Wang *et al.* 2014b, Wang *et al.* 2014c). Their repurposing for decentralised energy storage applications could therefore address two problems, by providing a more sustainable method of energy storage while also prolonging the useful life of these batteries. Given the barriers associated to the introduction of RETs that were identified in the survey work, it is plausible to assume that similar barriers may be associated to the introduction of repurposed Li-ion batteries, a technology which people may be unfamiliar with. Therefore in addition to the steps that would need to be taken to overcome the barriers to RET uptake, similar action may be needed to address those associated with the introduction of repurposed Li-ion batteries. The programs and policies that would be needed to address these barriers could be implemented concurrently promoting them as a joint development.

9.4. Estimating Future Demand

Using the findings of the rural energy surveys presented in Chapters 4 and 5, and a study by the World Bank, three different scenarios of rural household energy demand were developed and applied in Chapter 7. Comparisons of these scenarios allowed evaluation of how per capita energy demand varied depending upon the scope of the population being assessed. The changes in the populace assessed resulted in varying levels of per capita energy demand, which led to differences in the mass of battery required. This ultimately affected the end cost and level of GHG emissions which could be attributed to a project.

The findings show that in some circumstances a top down approach to estimating energy demand may not always be appropriate or accurate and that it is therefore vital to consider energy demand on a case by case basis to ensure the correct level of demand is ascertained in order to ensure any RET project installed is capable of delivering a reliable and sufficient energy supply.

These three scenarios were also used to model the wider environmental impacts resulting from the use of decentralised RETs to replace the fuels currently utilised by rural households using the integrated energy modelling tool LEAP. The results of which are presented in Chapter 8.

Small differences in the parameters applied to each of the models had a significant effect on the results and conclusions drawn from them. These differences are the result of the variation in the populations that each of the three scenarios is based on. This highlights again that a top down approach to estimating energy demand is not always appropriate as even small changes in the model parameters can have a significant effect on the results meaning they are not always representative and can result in inaccurate conclusions being drawn.

The most important parameters identified through the models which affected their outcomes were household population size, the types of fuels used as well as the extent to which they were used.

The modelling conducted in LEAP showed that the introduction of RETs caused the rate of total energy demand growth to increase as it allowed a faster transition to higher per capita energy provision. This increase was however dependent upon the fuels being replaced; fuels that represented a larger proportion of total energy demand increased this growth.

The use of RETs was also shown to cause the displacement of other fuels from the national energy mix, reducing their contribution to total primary fuel consumption. This ultimately could reduce dependency on unsustainable or imported energy sources by diversifying the countries energy mix, which has been shown to be essential in improving energy security both at a national and household level (Bull 2001, Karytsas & Theodoropoulou 2014, Martinot *et al.* 2002, Ölz *et al.* 2007).

A substantial reduction in total CO_{2e} emissions was also observed when RETs were incorporated into the models developed in Chapter 8 for each scenario; however the extent of these reductions was dependent on the fuels they were replacing. The targeting of specific fuels rather than activities may lead to higher volumes of CO_2e being avoided in the long term.

Despite the levels of total CO_2e being avoided, the volume of CO_2e that could be attributed to an RET system as a result of battery manufacture, meant that even after 11 years an RET system was still not be making a net carbon saving because under some scenarios insufficient levels of CO_2e had been mitigated. Scenarios where the levels of CO_2e avoided could offset the contribution from batteries were those where the fuels being displaced made a greater contribution to total energy demand.

Even in these scenarios the results from the LCA conducted in this work indicated that the mass of the battery would be restricted, thus only allowing sufficient energy to be stored to meet the level of demand for one or two days. This could result in supply issues if there is a prolong period where generation is disrupted, and could also affect the lifespan of a battery as frequent deep discharges has been shown to result in the shortening of a batteries life (Díaz-González *et al.* 2012, Kousksou *et al.* 2014, Sullivan & Gaines 2010).

However the results for the LCA of repurposed Li-ion batteries (Chapter 7.3) showed that their use in a RET system could avoid the need to offset any attributed CO_2e emissions before a net CO_2e saving is made, as they potentially could have already been completed offset during the use phase of the batteries first life. As a result, a larger battery could be used to store sufficient energy for a longer period without the negative implications, and also avoiding potential complications.

9.5. Recommendations

Given the findings of this work it is recommended that in order to successfully implement a RET system in a rural community of a developing country for the purpose of delivering modern energy services for household use, the following approach should be taken.

Firstly steps need to be taken by the local or national government to design and put in place comprehensive and robust policies to support not only the implementation but the ongoing use of RETs. These policies should primarily set the framework by which RET projects can be financially supported, not just to facilitate their setup but also their ongoing use and maintenance. The provision of development grants, affordable loans and subsidies should all be considered. In addition policy makers should include considerations to enable the Clean Development Mechanism (CDM) to be exploited. The CDM is a potential option for overcoming the barrier cost might pose in some poorer communities by facilitating the procurement of RETs or batteries for energy storage in exchange for ‘certified emission reduction’ (CER) credits (Akella *et al.* 2009, Kaygusuz 2012, UNFCCC 2014). This scheme could be used in assisting with the installation and operation of RET systems, helping address issues of acceptance which were identified in Chapters 4 and 5, by reducing or removing the costs. Particularly in developing countries this would prove valuable as financial institutions and private investors are also often reluctant to provide funding for small scale projects that are associated with such risks (Del Río 2007, Painuly 2001).

When planning projects each should be considered independently and examined on a case by case basis. Assuming the costs can be mitigated solar panels or wind turbines are the recommended technologies to use, final selection to be made based on assessment of conditions at the intended site of installation. Geothermal and hydro systems are ruled out because of the very specific conditions they require which meaning their use is geographical limited. Repurposed Li-ion batteries from automotive applications should be selected as the means by which energy generated within the system can be stored. Use of these batteries will also ensure that a project will start making a positive contribution to CO_2e mitigation sooner if not immediately.

Once a target populace have been identified the first step should be to carry out an energy survey to assess their current energy needs and the opportunities that exist for the use of RETs. This survey should also incorporate questions to ascertain the respondent's knowledge of RETs as well as their attitudes towards their potential introduction. Where possible these surveys should be carried out by people from the local community as this will aid in obtaining accurate responses, making respondents feel at ease and reducing scepticism as to the purpose of the surveys, especially if foreign agencies are involved. An additional benefit of these surveys is that from a very early stage it will help people feel included in the process which has been shown to aid in overcoming many barriers (Moomow *et al.* 2011).

The results of the survey detailing energy use should be incorporated into an energy modelling tool such as LEAP to enable modelling of the predicted growth in energy demand and CO_2e emissions. The modelling will also enable identification of the fuels which make the highest contribution to primary energy demand and have the highest GWP, this will allow for targeted replacement of fuels in order to have the greatest impact.

Assessment of the survey results will also allow for key barriers to be identified which can then be used to inform an education program which should be implemented prior to any other action at the site. This education program should address the major concerns that were highlighted by the respondents, while also outlining the long and short term benefits the use of RETs and repurposed batteries will directly have for them as energy consumers, as well as the local economy and environment plus the wider global community. The results of the energy forecast modelling could also be used as part of these educational programs to demonstrate the unseen benefits of using RETs. These sessions should also enable question or further concerns to be raised and addressed.

In addition it is recommended that funds are made available to employ and provide training to members of the target community to be responsible for the ongoing maintenance of a RET system once complete.

Selection of the site within a village for a system to be installed should focus on identifying brown field sites or contaminated land. Options should be put to the target populace to determine the most acceptable site. Where practical all planning decisions should incorporate participation by the target populace to install a sense of ownership in the project, which will help improve acceptance and the long term viability of a project.

The capacity of an installation should be above that which is determined from the energy forecasting model to ensure a project is future proof and able to meet any growth in demand. The UN's global mean for per capita energy consumption (21.98 MWh) should be considered as starting target. After installation a follow up assessments should be carried out to explore changes in energy demand to see if there is a need to increase capacity to ensure no disruption to supply.

The final recommendation is to re-interview participants to obtain testimonials about their experiences of the project which can be used in future project to demonstrate the benefits. These can also be used inform policy design and improve the delivery of future projects.

9.6. Summary Of Thesis Findings

There is still a substantial need for modern energy services in developing countries, particularly in rural communities. The use of RETs, particularly solar and wind technologies, provide an ideal means by which decentralised modern energy access can be delivered to these communities. However, they are not without their problems with energy storage systems being identified as an area of potential negative impacts.

Acceptance is the major barrier to the uptake of RETs, with financial constraints and a lack of knowledge and understanding being the factors behind this. Despite this, interest was shown in the use of RETs by rural communities in India. Therefore suitable education programs and financial assistance will improve the progressive attitude of a community, improving opportunities for and removing barriers to the uptake of RETs.

The correct application of decentralised RETs for modern energy provision can result in significant socioeconomic and environmental benefits. Not just as a direct result of the energy services being delivered, but by mitigating many of the impacts associated with the use of conventional means of energy provision, in particular the emission of GHGs.

In order to ensure this each RET project needs to be assessed on a case by case basis, with the needs of the target populace explored to identify the specific opportunities and barriers that exist, in order to allow for targeted action to be taken. Only then will the long term viability of a project be assured.

9.7. Future Work

The next stage of this work would be to take the recommendations outlined and apply them to real world scenarios in a developing country to see how effective they are at improving attitudes towards RETs. This however would need to be a long term project given the time it could take to develop the necessary policies and initiatives.

An alternative line of investigation could be to model the actual changes of energy demand and consumption in a village prior to the installation of a RET and after. This will allow for a better indication of how the uptake of RETs impacts on these factors and how they contribute to rural development.

Appendices

Appendix 1: Results Of Binomial Logistic Regression & Fisher's Exact Test Analysis Of Outcome Variables From Rural Energy Survey Of Orissa.

A.1.1 Outcome Variable 1: Aware of the term renewable or sustainable energy?

Questions			No. of Respondents		β	S.E.	p	OR	High CI	Low CI	Fisher's Exact Test (p)
			No	Yes							
District	Khordha		40	45				*Reference*			
	Cuttack		10	2							0.03
Village	Tamando	No	41	28				*Reference*			
		Yes	9	19	1.13	0.47	0.02	3.09	7.81	1.22	
	Dadhapatna	No	40	45				*Reference*			
		Yes	10	2							0.03
Head of household responsible for deciding fuel use?	No		20	34				*Reference*			
	Yes		30	13	-1.37	0.44	<0.01*	0.25	0.6	0.02	
Gender responsible for deciding household fuel used?	Female		15	26				*Reference*			
	Male		24	8	-1.65	0.52	<0.01*	0.19	0.53	0.01	
	Shared Responsibility		9	13	-0.18	0.54	0.74	0.83	2.41	0.06	
Reason for using main fuel for household lighting?	Cheap	No	19	37				*Reference*			
		Yes	31	10	-1.8	0.46	<0.01*	0.17	0.41	0.07	
	Easily available	No	7	18				*Reference*			
		Yes	43	29	-1.34	0.51	0.01	0.26	0.71	0.1	
Reasons unhappy with main fuel for household lighting?	Expensive	No	49	36				*Reference*			
		Yes	1	11							<0.01*
What other energy sources are used for Household lighting?	Candles	No	26	34				*Reference*			
		Yes	24	13	-0.88	0.43	0.04	0.41	0.97	0.18	
Paraffin/kerosene available for household lighting but not used	No		34	18				*Reference*			
	Yes		4	20							<0.01*
Reasons why paraffin/kerosene not used for household lighting?	Smokey	No	4	5				*Reference*			
		Yes	0	15							0.01
Reasons for using main fuel for household cooking?	Cheap	No	9	22	*Reference*						
		Yes	41	25	-1.39	0.47	<0.01*	0.25	0.63	0.1	
What other energy sources used for household cooking?	Firewood/biomass	No	40	27				*Reference*			
		Yes	10	20	1.09	0.46	0.02	2.96	7.31	1.2	
	Paraffin/kerosene	No	32	18				*Reference*			
		Yes	18	29	1.05	0.42	0.01	2.86	6.53	1.26	
	No other source used	No	28	42				*Reference*			
		Yes	22	5	-1.89	0.55	<0.01*	0.15	0.45	0.05	
Reasons why other energy source used for household cooking?	When raining	No	46	34				*Reference*			
		Yes	4	13							0.02
	Depends on fuels available	No	49	40				*Reference*			
		Yes	1	7							0.03
Individual fuels used for household cooking and volume of consumption	Firewood/biomass	kg/month	40	37	-0.005	0.002	0.01	0.995	0.999	0.99	
Reasons why paraffin/kerosene not used for household cooking?	Expensive	No	10	6				*Reference*			
		Yes	3	12							0.03
LPG available for household cooking but not used	No		16	29				*Reference*			
	Yes		26	8	-1.77	0.51	<0.01*	0.17	0.46	0.06	
Electricity available for household cooking but not used	No		12	22				*Reference*			
	Yes		30	15	-1.3	0.48	0.01	0.27	0.7	0.11	
Firewood/biomass available for household cooking but not used	No		37	25				*Reference*			
	Yes		5	12	1.27	0.59	0.03	3.55	11.33	1.11	
Fuels the household has to purchase and monthly expenditure of specific fuels	Firewood spend per month		27	27							
	Electricity	No	20	29				*Reference*			
		Yes	30	18	-0.88	0.42	0.03	0.41	0.94	0.18	
Which of the following appliances do you have, would like to have, or don't want?	Kettle	Have	17	33				*Reference*			
		Do not want	32	12	-1.64	0.45	<0.01*	0.19	0.47	0.08	
	Telephone	Have	36	43				*Reference*			
		Do not want	8	1							0.03
		Want	6	3							
Are there any other sources of household income?	No		48	37				*Reference*			
	Yes		2	10							0.01
How much is spent each month on necessities for the household?	Health care	No	19	32				*Reference*			
		Yes	31	15	-1.25	0.43	<0.01*	0.29	0.66	0.12	
Would you switch and pay slightly more for energy from renewable or sustainable sources if: you knew it was helping protect local environment?	No		21	33				*Reference*			
	Yes		28	14	-1.15	0.43	0.01	0.32	0.74	0.14	
Would you switch and pay slightly more for energy from renewable or sustainable sources if: you knew it was safer and more reliable?	No		19	34				*Reference*			
	Yes		30	13	-1.42	0.44	<0.01*	0.24	0.57	0.1	
Would you pay part of the set up costs for a renewable or sustainable energy supply if it meant: a safer supply?	No		27	35				*Reference*			
	Yes		22	12	-0.87	0.44	0.05	0.42	1	0.18	
Would you pay part of the set up costs for a renewable or sustainable energy supply if it meant: a more reliable supply?	No		25	35				*Reference*			
	Yes		24	12	-1.03	0.44	0.02	0.36	0.85	0.15	

A.1.2. Outcome Variable 2: Do you think communities like your own should be provided with these types of alternative [renewable or sustainable] energy supplies?

Questions			No. of Respondents No	No. of Respondents Yes	β	S.E.	p	OR	High CI	Low CI	Fisher's Exact Test *(p)*
Main material used for roofing	Bamboo	No	5	71				*Reference category*			
		Yes	4	9							0.02
Reasons for using main fuel for household cooking?	Cannot afford other fuels	No	3	62				*Reference category*			
		Yes	6	21							0.02
	Familiar fuel	No	7	32				*Reference category*			
		Yes	2	51							0.04
Examples of renewable or sustainable energy sources identified	Solar panels	No	3	6				*Reference category*			
		Yes	1	37							0.02
Means of renewable or sustainable energy generation heard of?	Hydroelectricity	No	5	19				*Reference category*			
		Yes	4	64							0.05
	Solar Panels	No	8	17				*Reference category*			
		Yes	1	66							<0.01*
Energy sources identified that respondents believed would be beneficial as an energy supply	Biogas	No	6	17				*Reference category*			
		Yes	3	66							0.01
	Solar power	No	8	24				*Reference category*			
		Yes	1	59							<0.01*
	Would be no benefit	No	5	72				*Reference category*			
		Yes	4	11							0.04
Do you think these types of energy should be used over current means of energy provisions?	No		7	16				*Reference category*			
	Yes		2	63							<0.01*
Would you switch if same price for energy from renewable or sustainable sources if: you knew it was helping protect local environment?	No		4	8				*Reference category*			
	Yes		5	73							0.02
Would you switch if same price for energy from renewable or sustainable sources if: you knew it was safer and more reliable?	No		5	4				*Reference category*			
	Yes		4	77							<0.01*
Would you switch and pay slightly more for energy from renewable or sustainable sources if: you knew it was helping protect local environment?	No		8	42				*Reference category*			
	Yes		1	40							0.04
Would you switch and pay slightly more for energy from renewable or sustainable sources if: you knew it was safer and more reliable?	No		8	41				*Reference category*			
	Yes		1	41							0.03

A.1.3 Outcome Variable 3: Do you think these types of energy [renewable/sustainable] should be used over current means of energy provision?

Questions			No. of Respondents: No	No. of Respondents: Yes	β	S.E.	p	OR	High CI	Low CI	Fisher's Exact Test *(p)*
Main material used for roofing?	Concrete	No	22	38				*Reference*			
		Yes	3	26							0.01
Main material used for walls?	Cement	No	9	46				*Reference*			
		Yes	16	18							<0.01*
Main material used for flooring?	Cement	No	6	38				*Reference*			
		Yes	19	26	-1.53	0.53	<0.01*	0.22	0.61	0.08	
	Concrete	No	23	44				*Reference*			
		Yes	2	20							0.03
Reason for using main fuel for household lighting?	Cheap	No	22	33				*Reference*			
		Yes	3	34							<0.01*
Reasons unhappy with main fuel for household lighting?	Unreliable	No	19	64				*Reference*			
		Yes	6	3							0.01
Time spent cooking per 24 hours?			25	67	0.78	0.27	<0.01*	2.18	3.68	1.29	
Are you happy with the main fuel used for household cooking?	No		14	22				*Reference*			
	Yes		11	45	0.96	0.48	0.05	2.6	6.66	1.02	
Reasons unhappy with main fuel for household cooking?	Smoky	No	11	49				*Reference*			
		Yes	14	18	-1.24	0.49	0.01	0.29	0.75	0.11	
Fuels the household has to purchase and monthly expenditure of specific fuels	Electricity	No	17	29				*Reference*			
		Yes	8	38	1.02	0.49	0.04	2.78	7.34	1.06	
How much is spent each month on necessities for the household?	Clothes	No	13	11				*Reference*			
		Yes	12	56	1.71	0.52	<0.01*	5.52	15.24	2	
	Health care	No	21	26				*Reference*			
		Yes	4	41							<0.01*
Means of renewable or sustainable energy generation heard of?	Solar Panels	No	14	12				*Reference*			
		Yes	11	55	1.76	0.51	<0.01*	5.83	15.96	2.13	
Energy sources identified that respondents believed would be beneficial as an energy supply	Biogas	No	13	13				*Reference*			
		Yes	12	54	1.5	0.51	<0.01*	4.5	12.12	1.67	
	Solar power	No	18	16				*Reference*			
		Yes	7	51	2.1	0.53	<0.01*	8.2	23.15	2.9	
	Would be no benefit	No	14	61				*Reference*			
		Yes	11	6	-2.08	0.59	<0.01*	0.13	0.4	0.04	
Do you think communities, like yours should be provided alternative energy supplies?	No		7	2				*Reference*			
	Yes		16	63							<0.01*
Would you switch if same price for energy from renewable or sustainable sources if: you knew it was helping protect local environment?	No		7	5				*Reference*			
	Yes		18	61	1.56	0.64	0.02	4.74	16.77	1.34	
Would you switch if same price for energy from renewable or sustainable sources if: you knew it was safer and more reliable?	No		6	4				*Reference*			
	Yes		19	62							0.02
Would you switch and pay slightly more for energy from renewable or sustainable sources if: you knew it was helping protect local environment?	No		24	26				*Reference*			
	Yes		1	40							<0.01*
Would you switch and pay slightly more for energy from renewable or sustainable sources if: you knew it was safer and more reliable?	No		23	26				*Reference*			
	Yes		2	40							<0.01*
Would you pay part of the set up costs for a renewable or sustainable energy supply if it meant: a cheaper supply?	No		12	11				*Reference*			
	Yes		13	55	1.53	0.52	<0.01*	4.62	12.76	1.67	
Would you pay part of the set up costs for a renewable or sustainable energy supply if it meant: a more reliable supply?	No		22	34				*Reference*			
	Yes		3	32							<0.01*

A.1.4. Outcome Variable 4: Would you pay part of set-up costs for a renewable or sustainable energy supply if it meant: cheaper supply?

Questions			No. of Respondents: No	No. of Respondents: Yes	β	S.E.	p	OR	High CI	Low CI	Fisher's Exact Test *(p)*
Number of rooms in the household?			26	70	0.22	0.11	0.05	1.24	1.54	1.00	
Head of household responsible for deciding fuel use?	No		20	34				*Reference*			
	Yes		6	36	1.26	0.52	0.02	3.53	9.84	1.27	
Number of windows in the household?			24	67	0.21	0.10	0.03	1.23	1.49	1.02	
Main fuel for used for household lighting	Electricity		19	65				*Reference*			
	Firewood/biomass		2	0							0.01
	Paraffin/kerosene		5	5							
Reasons unhappy with main fuel for household lighting	Unreliable	No	19	67				*Reference*			
		Yes	7	3							<0.01*
Reasons why other energy source used for household lighting?	During power cut	No	5	2				*Reference*			
		Yes	16	58							0.01
What light sources do you use and how many?	Electric lights	No	6	4				*Reference*			
		Yes	20	66							0.02
Total Number of household electrical Lights			26	70	0.20	0.08	0.02	1.22	1.44	1.03	
What other energy sources used for household cooking	Firewood/biomass	No	23	43				*Reference*			
		Yes	3	27							0.01
Individual fuels used for household cooking and volume of consumption	Paraffin/kerosene	Litres per month	11	41	0.64	0.29	0.03	1.89	3.34	1.07	
Reasons electricity not used for household cooking despite availability	Not easily available	No	10	29				*Reference*			
		Yes	4	1							0.03
Is equipment used for household cooling powered by electricity?	No		6	3				*Reference*			
	Yes		19	66							0.01
Fuels the household has to purchase and monthly expenditure of specific fuels	Total household fuel expense per month		25	70	0.001	0.001	0.02	1.0014	1.0026	1.0002	
How much is spent each month on necessities for the household?	Clothes	No	13	13				*Reference*			
		Yes	13	57	1.48	0.50	<0.01*	4.38	11.64	1.65	
	Health care	No	20	31				*Reference*			
		Yes	6	39	1.43	0.52	0.01	4.19	11.71	1.50	
Total household monthly expenditure (excluding fuels)?			26	70	0.00012	0.00006	0.03	1.00012	1.00023	1.00001	
Means of renewable or sustainable energy generation heard of?	Solar Panels	No	13	16				*Reference*			
		Yes	13	54	1.22	0.48	0.01	3.37	8.73	1.31	
Energy sources identified that respondents believed would be beneficial as an energy supply	Solar power	No	16	21				*Reference*			
		Yes	10	49	1.32	0.48	0.01	3.73	9.57	1.46	
	Would be no benefit	No	17	61				*Reference*			
		Yes	9	9	-1.28	0.55	0.02	0.28	0.81	0.10	
Do you think these types of energy should be used over current means of energy provisions?	No		12	13				*Reference*			
	Yes		11	55	1.53	0.52	<0.01*	4.62	12.76	1.67	
Would you switch if same price for energy from renewable or sustainable sources if: you knew it was helping protect local environment?	No		7	7				*Reference*			
	Yes		18	63	1.25	0.60	0.04	3.50	11.29	1.08	
Would you switch and pay slightly more for energy from renewable or sustainable sources if: you knew it was helping protect local environment?	No		23	31				*Reference*			
	Yes		3	39							<0.01*

A.1.5. Outcome Variable 5: Would you pay part of set-up costs for a renewable or sustainable energy supply if it meant: safer supply?

Questions			No. of Respondents No	No. of Respondents Yes	β	S.E.	p	OR	High CI	Low CI	Fisher's Exact Test *(p)*
Village	Shishupal-Garh	No	58	26				*Reference*			
		Yes	4	8							0.02
Number of rooms in the household?			62	34	0.22	0.08	0.01	1.25	1.46	1.07	
Head of household responsible for deciding fuel use?	No		44	10				*Reference*			
	Yes		18	24	1.77	0.47	<0.01*	5.87	14.71	2.34	
Gender responsible for selecting fuels used in household?	Female		36	5				*Reference*			
	Male		13	18	2.30	0.60	<0.01*	9.97	32.33	3.07	
	Shared Responsibility		13	9	1.61	0.64	0.01	4.98	17.64	1.41	
Main material used for roofing?	Straw/Thatched	No	44	31				*Reference*			
		Yes	17	1							<0.01*
	Concrete	No	50	13				*Reference*			
		Yes	11	19	1.89	0.49	<0.01*	6.64	17.37	2.54	
Main material used for flooring	Mud	No	39	29				*Reference*			
		Yes	22	3							0.01
How many level is the whole building spread over?			61	32	1.56	0.49	<0.01*	4.78	12.41	1.84	
Number of windows in the household?			58	33	0.32	0.09	<0.01*	1.38	1.63	1.16	
Reason for using main fuel for household lighting?	Cheap	No	47	9				*Reference*			
		Yes	15	25	2.16	0.49	<0.01*	8.70	22.69	3.34	
	Easily available	No	20	4				*Reference*			
		Yes	42	30							0.03
Are you happy with main fuel for household lighting?	No		27	4				*Reference*			
	Yes		34	30							<0.01*
Reasons why other energy source used for household lighting?	During power cut	No	7	0				*Reference*			
		Yes	42	32							0.04
Paraffin/kerosene available for household lighting but not used	No		30	22				*Reference*			
	Yes		20	4							0.04
What light sources do you use and how many?	Electric lights	No	10	0				*Reference*			
		Yes	52	34							0.01
	(Fuel lamps) L/24hours		52	26	2.20	1.04	0.03	9.05	69.09	1.19	
Total Number of household electrical Lights?			62	34	0.23	0.07	<0.01*	1.26	1.46	1.09	
Time spent cooking per 24 hours?			62	34	0.57	0.18	<0.01*	1.76	2.50	1.24	
Main fuel for used for household cooking	Firewood/biomass		49	13				*Reference*			
	LP gas		12	18	1.73	0.49	<0.01*	5.65	14.66	2.18	
Reasons for using main fuel for household cooking	Cannot afford other fuels	No	35	32				*Reference*			
		Yes	27	2							<0.01*
Are you happy with the main fuel used for household cooking	No		33	4				*Reference*			
	Yes		29	30							<0.01*
Reasons unhappy with main fuel for household cooking	Smoky	No	31	32				*Reference*			
		Yes	31	2							<0.01*
Reasons why other energy source used for household cooking	When raining	No	47	33				*Reference*			
		Yes	15	1							0.01
	Primary fuel unavailable	No	48	18				*Reference*			
		Yes	14	16	1.11	0.46	0.02	3.05	7.49	1.24	
Individual fuels used for household cooking and volume of consumption	Paraffin/kerosene	No	33	8				*Reference*			
		Yes	29	26	1.31	0.48	0.01	3.70	9.43	1.45	
		Litres per month	26	26	0.26	0.13	0.05	1.30	1.69	1.00	
	LPG	No	44	11				*Reference*			
		Yes	18	23	1.63	0.46	<0.01*	5.11	12.62	2.07	
Paraffin/kerosene available for household cooking but not used	No		23	24				*Reference*			
	Yes		26	5	-1.69	0.57	<0.01*	0.18	0.56	0.06	
Candles available for household cooking but not used	No		31	25				*Reference*			
	Yes		18	4							0.04

No other energy sources available	No		49	29				*Reference*			
	Yes		13	5							<0.01*
Over 24 hours how long do you typically use fans/air conditioning to cool household?	During Summer		62	34	0.11	0.04	<0.01*	1.12	1.20	1.04	
Is equipment used for household cooling powered by electricity?	No		9	0				*Reference*			
	Yes		51	34							0.02
Fuels the household has to purchase and monthly expenditure of specific fuels	Firewood	No	22	21				*Reference*			
		Yes	40	13	-1.08	0.44	0.01	0.34	0.81	0.14	
	LPG	No	44	15				*Reference*			
		Yes	18	19	1.13	0.44	0.01	3.10	7.40	1.30	
	Paraffin/kerosene	No	29	5				*Reference*			
		Yes	33	29	1.63	0.55	<0.01*	5.10	14.89	1.74	
	Electricity	No	43	5				*Reference*			
		Yes	19	29	2.57	0.56	<0.01*	13.13	39.12	4.40	
	Total household fuel expense per month		61	34	0.0011	0.0004	0.01	1.0010	1.0019	1.0003	
Does household have to buy all the fuels used?	No		39	12		Reference					
	Yes		23	22	1.13	0.44	0.01	3.11	7.43	1.30	
Household income	Total household weekly income (from employment)		57	33	0.0002	0.0001	0.03	1.0002	1.0004	1.0000	
	Male weekly income		56	31	0.0002	0.0001	0.05	1.0002	1.0004	1.0000	
Are these any other sources of household income?	No		58	27				*Reference*			
	Yes		4	7							0.05
Total household income per month			62	34	0.00006	0.00002	0.01	1.00006	1.00010	1.00001	
How much is spent each month on necessities for the household?	Food monthly expense		61	33	0.0002	0.0001	<0.01*	1.0000	1.0004	1.0001	
	Transport	No	25	5				*Reference*			
		Yes	37	29	1.37	0.55	0.01	3.92	11.50	1.34	
	Transport monthly expense		33	29	0.0004	0.0002	0.05	1.0004	1.0009	1.0000	
	Education monthly expense		38	23	0.0003	0.0001	0.02	1.0003	1.0006	1.0000	
	Clothes	No	24	2				*Reference*			
		Yes	38	32							<0.01*
	Health care	No	48	3				*Reference*			
		Yes	14	31							<0.01*
Total household monthly expenditure (excluding fuels)			62	34	0.00016	0.00004	<0.01*	1.00016	1.00025	1.00007	
Respondent aware of the term 'renewable or sustainable energy'?	No		27	22				*Reference*			
	Yes		35	12	-0.87	0.44	0.05	0.42	1.00	0.18	
Means of renewable or sustainable energy generation heard of?	Solar Panels	No	25	4				*Reference*			
		Yes	37	30							<0.01*
Energy sources identified that respondents believed would be beneficial as an energy supply	Solar power	No	33	4				*Reference*			
		Yes	29	30							<0.01*
Do you have a preferred renewable or sustainable energy source?	No		53	20				*Reference*			
	Yes		9	12	1.26	0.51	0.01	3.53	9.66	1.29	
What is your preferred energy source?	Biogas		7	2				*Reference*			
	Solar		2	8							0.02
Would you switch and pay slightly more for energy from renewable or sustainable sources if: you knew it was helping protect local environment?	No		53	1				*Reference*			
	Yes		9	33							<0.01*
Would you switch and pay slightly more for energy from renewable or sustainable sources if: you knew it was safer and more reliable?	No		51	2				*Reference*			
	Yes		11	32							<0.01*
Would you pay part of the set up costs for a renewable or sustainable energy supply if it meant: a more reliable supply?	No		59	1				*Reference*			
	Yes		3	33							<0.01*

A.1.6. Outcome Variable 6: Would you pay part of set-up costs for a renewable or sustainable energy supply if it meant: more reliable supply?

Questions			No. of Respondents No	No. of Respondents Yes	β	S.E.	p	OR	High CI	Low CI	Fisher's Exact Test *(p)*
Village	Dihapura	No	50	35				*Reference*			
		Yes	10	1							0.05
Number of rooms in the household?			60	36	0.18	0.08	0.02	1.20	1.39	1.04	
Head of household responsible for deciding fuel use?	No		43	11				*Reference*			
	Yes		17	25	1.75	0.46	<0.01*	5.75	14.20	2.33	
Gender responsible for selecting fuels used in household?	Female		35	6				*Reference*			
	Male		13	18	2.09	0.57	<0.01*	8.08	24.80	2.63	
	Shared Responsibility		12	10	1.58	0.62	0.01	4.86	16.24	1.46	
Main material used for roofing?	Straw/Thatched	No	43	32				*Reference*			
		Yes	16	2							0.01
	Concrete	No	48	15		Reference					
		Yes	11	19	1.71	0.48	<0.01*	5.53	14.18	2.15	
Main material used for flooring?	Mud	No	37	31				*Reference*			
		Yes	22	3							<0.01*
	Concrete	No	55	16				*Reference*			
		Yes	4	18							<0.01*
How many levels is the whole building spread over?			59	34	1.45	0.48	<0.01*	4.26	10.88	1.66	
Number of windows in the household?			56	35	0.29	0.08	<0.01*	1.34	1.58	1.14	
Reason for using main fuel for household lighting?	Cheap	No	45	11				*Reference*			
		Yes	15	25	1.92	0.47	<0.01*	6.82	17.09	2.72	
	Easily available	No	20	4				*Reference*			
		Yes	40	32							0.02
Are you happy with main fuel for household lighting?	No		26	5				*Reference*			
	Yes		33	31	1.59	0.55	<0.01*	4.88	14.32	1.67	
Paraffin/kerosene available for household lighting but not used?	No		29	23				*Reference*			
	Yes		21	3							0.01
Total Number of household electrical Lights?			60	36	0.21	0.07	<0.01*	1.24	1.42	1.07	
Time spent cooking per 24 hours			60	36	0.46	0.17	0.01	1.59	2.23	1.14	
Main fuel for used for household cooking?	Firewood/biomass		47	15				*Reference*			
	LP gas		12	18	1.55	0.48	<0.01*	4.70	11.95	1.85	
Reasons for using main fuel for household cooking?	Cannot afford other fuels	No	34	33				*Reference*			
		Yes	26	3							<0.01*
Are you happy with the main fuel used for household cooking?	No		31	6				*Reference*			
	Yes		29	30	1.68	0.52	<0.01*	5.34	14.71	1.94	
Reasons unhappy with main fuel for household cooking	Health Concerns	No	37	34				*Reference*			
		Yes	23	2							<0.01*
	Smoky	No	31	32				*Reference*			
		Yes	29	4							<0.01*
	Unreliable	No	43	34				*Reference*			
		Yes	17	2							0.01
	Unsafe	No	40	34				*Reference*			
		Yes	20	2							<0.01*
Reasons why other energy source used for household cooking	Primary fuel unavailable	No	46	20				*Reference*			
		Yes	14	16	0.97	0.45	0.03	2.63	6.39	1.08	
Individual fuels used for household cooking and volume of consumption	Paraffin/kerosene	No	31	10				Reference			
		Yes	29	26	1.02	0.45	0.02	2.78	6.75	1.14	
	LPG	No	42	13				*Reference*			
		Yes	18	23	1.42	0.45	<0.01*	4.13	9.91	1.72	
Paraffin/kerosene available for household cooking but not used	No		22	25				*Reference*			
	Yes		26	5	-1.78	0.57	<0.01*	0.17	0.52	0.06	
Candles available for household cooking but not used	No		30	26				*Reference*			
	Yes		18	4							0.02
Over 24 hours how long do you typically use fans/air conditioning to cool household?	During Summer		60	36	0.11	0.04	<0.01*	1.11	1.19	1.04	

Fuels the household has to purchase and monthly expenditure of specific fuels	Firewood/biomass	No	21	22				*Reference*			
		Yes	39	14	-1.07	0.44	0.01	0.34	0.81	0.15	
	LPG	No	42	17				*Reference*			
		Yes	18	19	0.96	0.44	0.03	2.61	6.14	1.11	
	Paraffin/kerosene	No	27	7				*Reference*			
		Yes	33	29	1.22	0.49	0.01	3.39	8.94	1.29	
	Electricity	No	42	6				*Reference*			
		Yes	18	30	2.46	0.53	<0.01*	11.67	32.87	4.14	
	Total household fuel expense per month		59	36	0.0009	0.0004	0.01	1.0010	1.0017	1.0002	
Does household have to buy all the fuels used?	No		38	13				*Reference*			
	Yes		22	23	1.12	0.44	0.01	3.06	7.22	1.29	
Types and volume of fuels respondent obtains for free?	Biomass	No	41	35				*Reference*			
		Yes	18	1							<0.01*
Which of the following appliances do you have, would like to have, or don't want	Refrigerator	Have	19	24				*Reference*			
		Do not want	23	7	-1.42	0.53	0.01	0.24	0.68	0.09	
		Want	18	5	-1.51	0.59	0.01	0.22	0.70	0.07	
	Television	Have	41	33				*Reference*			
		Do not want	8	2							0.03
		Want	11	1							
How much is spent each month on necessities for the household?	Food monthly expense		59	35	0.00023	0.00008	<0.01*	1.00000	1.00039	1.00008	
	Education monthly expense		38	23	0.00032	0.00014	0.02	1.00000	1.00059	1.00004	
	Clothes	No	21	5				*Reference*			
		Yes	39	31	1.21	0.55	0.03	3.34	9.86	1.13	
	Health care	No	46	5				*Reference*			
		Yes	14	31	3.01	0.57	<0.01*	20.37	62.31	6.66	
Total household monthly expenditure (excluding fuels)			60	36	0.00015	0.00004	<0.01*	1.00015	1.00023	1.00006	
Respondent aware of the term 'renewable or sustainable energy'?	No		25	24				*Reference*			
	Yes		35	12	-1.03	0.44	0.02	0.36	0.85	0.15	
Means of renewable or sustainable energy generation heard of?	Solar Panels	No	23	6				*Reference*			
		Yes	37	30	1.13	0.52	0.03	3.11	8.61	1.12	
Energy sources identified that respondents believed would be beneficial as an energy supply	Solar power	No	30	7				*Reference*			
		Yes	30	29	1.42	0.49	<0.01*	4.14	10.91	1.57	
	Would be no benefit	No	44	34				*Reference*			
		Yes	16	2							0.01
Do you have a preferred renewable or sustainable energy source?	No		51	22				*Reference*			
	Yes		9	12	1.13	0.51	0.03	3.09	8.39	1.14	
What is your preferred energy source?	Biogas		7	2				*Reference*			
	Solar		2	8							0.02
Do you think these types of energy should be used over current means of energy provisions?	No		22	3				*Reference*			
	Yes		34	32							<0.01*
Would you switch and pay slightly more for energy from renewable or sustainable sources if: you knew it was helping protect local environment?	No		50	4				*Reference*			
	Yes		10	32							<0.01*
Would you switch and pay slightly more for energy from renewable or sustainable sources if: you knew it was safer and more reliable?	No		51	2				*Reference*			
	Yes		9	34							<0.01*
Would you pay part of the set up costs for a renewable or sustainable energy supply if it meant: a safer supply?	No		59	3				*Reference*			
	Yes		1	33							<0.01*

Appendix 2: Values & References Used To Calculated Mean Energy Density Of Varying Batteries.

	Battery type				Source
	PbA	NiCd	NIMH	Li ion	
Energy density (Wh/kg)	30.0				(Díaz-González et al. 2012)
	40.0	62.5		112.5	(Evans et al. 2012)
	30.0	32.5	80.0	115.0	(Hadjipaschalis et al. 2009)
	40.0	62.5		137.5	(Kousksou et al. 2014)
	39.0	54.0	80.0	120.0	(Råde & Andersson 2001)
	45.0				(Råde & Andersson 2001)
		52.5			(Rahman et al. 2012)
	26.0	26.0	45.0	100.0	(Sullivan & Gaines 2012)
	27.5	55.0	65.0	105.0	(Van den Bossche et al. 2006)
	35.0	45.0	62.5	125.0	(Yekini Suberu et al. 2014)
Mean	34.72	48.75	66.50	116.43	

Appendix 3: Parameters Used To Calculate Estimates Of Per Capita Energy Consumption Of The Archetypal Rural Households Based On The Rural Energy Surveys Completed In Maharashtra (Chapter 4) & Orissa (Chapter 5).

Parameters used to estimate per capita energy consumption of village of Uddhar in Maharashtra

Fuel/Appliance	Hours used	Volume consumed (kg/day)	Energy content (MJ/kg)	Efficiency (%)	Final consumption (Mj/kg)	Total MJ/day	Total kWh/day
4 Fluorescent lights (40watt)	6.1						0.976
3 Energy saving lights (9watt)	6.1						0.165
Kerosene		0.59	43	35	15.05	8.880	2.467
Firewood/biomass	4.4	2.5	14.6	13	1.898	4.745	1.318
	Hours used		Energy consumed (kWh/yr)	Energy consumed (Wh)			
Radio			32.9				0.090
Television			165.2				0.453
Mechanical fan	7.35			36.4			0.268
						Total	5.736
						per capita	1.434

Parameters used to estimate per capita energy consumption of village from Orissa

Fuel/Appliance	Hours used	Volume consumed (kg/day)	Energy content (MJ/kg)	Efficiency (%)	Final consumption (Mj/kg)	Total MJ/day	Total kWh/day
5 Energy saving lights (20watt)	5.05						0.505
2 kerosene lamps		0.082	43	35	15.05	1.234	0.686
Firewood/biomass		4.45	14.6	13	1.898	8.446	2.346
Kerosene		0.09	43	55	23.65	2.129	0.591
	Hours used		Energy consumed (kWh/yr)	Energy consumed (Wh)			
Mechanical fan	10.1			36.4			0.184
Refrigerator			567.7				1.555
Television			165.2				0.453
						Total	6.320
						per capita	1.053

Appendix 4: Independent-Sample T-Test Results For The Comparison Of The Energy Densities Of Different Chemical Storage System.

		Battery type														
		PbA			NiCd			NiMH			Li-ion			Repurposed Li-ion		
		T	df	p	T	df	p	T	df	p	T	df	p	T	df	p
Battery type	PbA	0	-	1	-2.68	9.98	0.02	-4.63	4.95	<0.01	-15.59	8.58	<0.01	-13.28	9.90	<0.01
	NiCd	-2.68	9.98	0.02	0	-	1	-2.21	8.07	0.06	-10.09	12.92	<0.01	-7.31	12.75	<0.01
	NiMH	-4.63	4.95	<0.01	-2.21	8.07	0.06	0	-	1	-6.20	7.91	<0.01	-3.54	6.68	0.01
	Li-ion	-15.59	8.58	<0.01	-10.09	12.92	<0.01	-6.20	7.91	<0.01	0	-	1	3.83	11.45	<0.01
	Repurposed Li-ion	-13.28	9.90	<0.01	-7.31	12.75	<0.01	-3.54	6.68	0.01	3.83	11.45	<0.01	0	-	1

Appendix 5: Changes In Energy Demand, Global Warming Potential & Primary Feedstock Fuels For Baseline & Individual Scenarios Applied To The Three Different Models Outlined In Chapter 8 Using LEAP.

A.5.1. Model 1:
Baseline Model.

		Year											
		2011*	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Household Energy demand (TWh)		6.77	11.90	17.03	22.15	27.28	32.41	37.54	42.66	47.79	52.92	58.04	63.17
Global Warming potential (Million tonne CO_2e)	Natural Gas	0.02	0.03	0.05	0.06	0.08	0.09	0.11	0.12	0.14	0.15	0.17	0.18
	Kerosene	0.23	0.40	0.57	0.74	0.91	1.08	1.25	1.42	1.59	1.76	1.93	2.10
	Oil	0.001	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.009	0.011	0.012	0.013
	Coal	0.21	0.37	0.53	0.70	0.86	1.02	1.18	1.34	1.50	1.66	1.82	1.98
	Biomass	0.14	0.24	0.35	0.45	0.56	0.66	0.77	0.87	0.98	1.08	1.19	1.29
	Total	0.60	1.05	1.50	1.95	2.41	2.86	3.31	3.76	4.21	4.67	5.12	5.57
Primary energy requirements (TWh)	Natural Gas	0.10	0.17	0.24	0.32	0.39	0.46	0.54	0.61	0.68	0.76	0.83	0.90
	Kerosene	0.86	1.51	2.16	2.81	3.45	4.10	4.75	5.40	6.05	6.70	7.35	8.00
	Oil	0.01	0.01	0.01	0.02	0.02	0.02	0.03	0.03	0.04	0.04	0.04	0.05
	Coal	0.63	1.12	1.60	2.08	2.56	3.04	3.52	4.00	4.48	4.96	5.44	5.92
	Wind	0.07	0.13	0.18	0.24	0.29	0.34	0.40	0.45	0.51	0.56	0.62	0.67
	Solar	0.004	0.007	0.010	0.013	0.016	0.019	0.022	0.025	0.028	0.031	0.034	0.036
	Hydro	0.15	0.26	0.37	0.48	0.59	0.70	0.81	0.93	1.04	1.15	1.26	1.37
	Nuclear	0.02	0.04	0.05	0.07	0.08	0.10	0.11	0.13	0.14	0.16	0.18	0.19
	Municipal Solid Waste	0.0005	0.0009	0.0012	0.0016	0.0020	0.0023	0.0027	0.0031	0.0034	0.0038	0.0042	0.0045
	Biomass	5.12	8.99	12.87	16.74	20.62	24.49	28.36	32.24	36.11	39.99	43.86	47.74
	Total	6.96	12.22	17.49	22.75	28.02	33.29	38.55	43.82	49.08	54.35	59.61	64.88

*baseline year before introduction of any decentralised RETs

Scenario 1: Fuels for household cooking substituted with RETs.

		Year											
		2011*	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Household Energy demand (TWh)		6.77	13.76	20.38	26.62	32.49	37.99	43.12	47.87	52.25	56.26	59.90	63.17
Global Warming potential (Million tonne CO_2e)	Natural Gas	0.02	0.03	0.05	0.06	0.08	0.09	0.11	0.12	0.14	0.15	0.17	0.18
	Kerosene	0.23	0.39	0.55	0.70	0.85	0.99	1.13	1.26	1.38	1.50	1.62	1.73
	Oil	0.001	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.009	0.011	0.012	0.013
	Coal	0.21	0.37	0.53	0.70	0.86	1.02	1.18	1.34	1.50	1.66	1.82	1.98
	Biomass	0.14	0.23	0.32	0.39	0.46	0.51	0.56	0.60	0.62	0.64	0.65	0.65
	Total	0.60	1.03	1.45	1.86	2.25	2.62	2.98	3.32	3.65	3.97	4.27	4.55
Primary energy requirements (TWh)	Natural Gas	0.10	0.17	0.24	0.32	0.39	0.46	0.54	0.61	0.68	0.76	0.83	0.90
	Kerosene	0.86	1.48	2.09	2.67	3.23	3.77	4.29	4.79	5.27	5.73	6.17	6.58
	Oil	0.01	0.01	0.01	0.02	0.02	0.02	0.03	0.03	0.04	0.04	0.04	0.05
	Coal	0.63	1.12	1.60	2.08	2.56	3.04	3.52	4.00	4.48	4.96	5.44	5.92
	Wind	0.07	0.71	1.34	1.97	2.60	3.24	3.87	4.50	5.14	5.77	6.40	7.03
	Solar	0.004	1.720	3.436	5.152	6.868	8.584	10.300	12.016	13.732	15.448	17.164	18.880
	Hydro	0.15	0.26	0.37	0.48	0.59	0.70	0.81	0.93	1.04	1.15	1.26	1.37
	Nuclear	0.02	0.04	0.05	0.07	0.08	0.10	0.11	0.13	0.14	0.16	0.18	0.19
	Municipal Solid Waste	0.0005	0.0009	0.0012	0.0016	0.0020	0.0023	0.0027	0.0031	0.0034	0.0038	0.0042	0.0045
	Biomass	5.12	8.59	11.70	14.47	16.88	18.94	20.65	22.02	23.03	23.68	23.99	23.95
	Total	6.96	14.08	20.84	27.22	33.23	38.86	44.13	49.02	53.55	57.70	61.47	64.88

*baseline year before introduction of any decentralised RETs

Scenario 2: Fuels for household lighting substituted with RETs.

		Year											
		2011*	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Household Energy demand (TWh)		6.77	12.14	17.46	22.73	27.95	33.13	38.25	43.33	48.36	53.35	58.28	63.17
Global Warming potential (Million tonne CO_2e)	Natural Gas	0.02	0.03	0.05	0.06	0.08	0.09	0.10	0.12	0.13	0.14	0.15	0.17
	Kerosene	0.23	0.38	0.53	0.67	0.80	0.92	1.03	1.13	1.22	1.29	1.36	1.42
	Oil	0.001	0.002	0.003	0.004	0.005	0.006	0.007	0.008	0.009	0.010	0.011	0.011
	Coal	0.21	0.37	0.53	0.68	0.83	0.98	1.12	1.27	1.41	1.54	1.68	1.81
	Biomass	0.14	0.24	0.35	0.45	0.56	0.66	0.77	0.87	0.98	1.08	1.19	1.29
	Total	0.60	1.03	1.46	1.87	2.27	2.66	3.03	3.39	3.74	4.07	4.39	4.70
Primary energy requirements (TWh)	Natural Gas	0.10	0.17	0.24	0.31	0.38	0.44	0.51	0.57	0.64	0.70	0.76	0.82
	Kerosene	0.86	1.46	2.03	2.56	3.05	3.50	3.92	4.29	4.63	4.93	5.19	5.42
	Oil	0.01	0.01	0.01	0.02	0.02	0.02	0.03	0.03	0.03	0.04	0.04	0.04
	Coal	0.63	1.11	1.57	2.03	2.47	2.92	3.35	3.77	4.19	4.60	5.01	5.40
	Wind	0.07	0.20	0.33	0.45	0.58	0.70	0.83	0.95	1.07	1.19	1.31	1.43
	Solar	0.004	0.228	0.451	0.675	0.898	1.122	1.345	1.568	1.792	2.015	2.238	2.461
	Hydro	0.15	0.26	0.36	0.47	0.57	0.68	0.78	0.87	0.97	1.07	1.16	1.25
	Nuclear	0.02	0.04	0.05	0.07	0.08	0.09	0.11	0.12	0.13	0.15	0.16	0.17
	Municipal Solid Waste	0.0005	0.0009	0.0012	0.0016	0.0019	0.0022	0.0026	0.0029	0.0032	0.0035	0.0038	0.0041
	Biomass	5.12	8.99	12.87	16.74	20.61	24.49	28.36	32.23	36.11	39.98	43.85	47.72
	Total	6.96	12.46	17.91	23.31	28.67	33.97	39.22	44.42	49.57	54.68	59.73	64.73

*baseline year before introduction of any decentralised RETs

Scenario 3: Fuels for household lighting & other appliances substituted with RETs.

		Year											
		2011*	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Household Energy demand (TWh)		6.77	12.37	17.88	23.28	28.60	33.82	38.95	43.98	48.92	53.76	58.51	63.17
Global Warming potential (Million tonne CO_2e)	Natural Gas	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.08	0.09	0.09	0.09	0.09
	Kerosene	0.23	0.38	0.53	0.67	0.80	0.92	1.03	1.13	1.22	1.29	1.36	1.42
	Oil	0.001	0.002	0.003	0.004	0.004	0.005	0.005	0.006	0.006	0.006	0.006	0.006
	Coal	0.21	0.36	0.49	0.60	0.70	0.79	0.86	0.91	0.96	0.98	0.99	0.99
	Biomass	0.14	0.24	0.35	0.45	0.56	0.66	0.77	0.87	0.98	1.08	1.19	1.29
	Total	0.60	1.02	1.41	1.78	2.13	2.45	2.74	3.00	3.24	3.46	3.64	3.80
Primary energy requirements (TWh)	Natural Gas	0.10	0.16	0.22	0.27	0.32	0.36	0.39	0.42	0.43	0.45	0.45	0.45
	Kerosene	0.86	1.46	2.03	2.56	3.05	3.50	3.92	4.29	4.63	4.93	5.19	5.42
	Oil	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02
	Coal	0.63	1.06	1.45	1.79	2.09	2.35	2.56	2.73	2.85	2.93	2.97	2.96
	Wind	0.07	0.27	0.46	0.64	0.82	1.00	1.17	1.33	1.49	1.65	1.80	1.95
	Solar	0.004	0.440	0.876	1.312	1.747	2.182	2.617	3.052	3.486	3.920	4.354	4.787
	Hydro	0.15	0.25	0.34	0.42	0.48	0.54	0.59	0.63	0.66	0.68	0.69	0.69
	Nuclear	0.02	0.03	0.05	0.06	0.07	0.08	0.08	0.09	0.09	0.09	0.10	0.10
	Municipal Solid Waste	0.0005	0.0008	0.0011	0.0014	0.0016	0.0018	0.0020	0.0021	0.0022	0.0023	0.0023	0.0023
	Biomass	5.12	8.99	12.86	16.73	20.60	24.47	28.34	32.21	36.07	39.93	43.80	47.66
	Total	6.96	12.68	18.29	23.80	29.20	34.50	39.69	44.77	49.74	54.61	59.37	64.02

*baseline year before introduction of any decentralised RETs

A.5.2. Model 2:

Baseline Model.

		Year											
		2011*	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Household Energy demand (TWh)		4.99	11.43	17.86	24.30	30.74	37.18	43.62	50.05	56.49	62.93	69.37	75.80
Global Warming potential (Million tonne CO_2e)	Natural Gas	0.01	0.03	0.05	0.07	0.08	0.10	0.12	0.14	0.15	0.17	0.19	0.21
	Kerosene	0.17	0.38	0.60	0.81	1.03	1.25	1.46	1.68	1.89	2.11	2.32	2.54
	Oil	0.001	0.002	0.003	0.005	0.006	0.007	0.008	0.009	0.011	0.012	0.013	0.014
	Coal	0.15	0.34	0.53	0.72	0.91	1.10	1.29	1.48	1.67	1.86	2.06	2.25
	Biomass	0.10	0.24	0.37	0.50	0.63	0.77	0.90	1.03	1.16	1.30	1.43	1.56
	Total	0.43	0.99	1.55	2.11	2.66	3.22	3.78	4.34	4.89	5.45	6.01	6.57
Primary energy requirements (TWh)	Natural Gas	0.07	0.15	0.24	0.33	0.41	0.50	0.59	0.67	0.76	0.85	0.93	1.02
	Kerosene	0.64	1.46	2.28	3.10	3.92	4.74	5.57	6.39	7.21	8.03	8.85	9.67
	Oil	0.004	0.008	0.013	0.017	0.022	0.027	0.031	0.036	0.040	0.045	0.050	0.054
	Coal	0.44	1.01	1.58	2.15	2.72	3.29	3.86	4.42	4.99	5.56	6.13	6.70
	Wind	0.05	0.11	0.18	0.24	0.31	0.37	0.44	0.50	0.57	0.63	0.70	0.76
	Solar	0.003	0.006	0.010	0.013	0.017	0.020	0.024	0.027	0.031	0.034	0.038	0.041
	Hydro	0.10	0.23	0.37	0.50	0.63	0.76	0.89	1.03	1.16	1.29	1.42	1.55
	Nuclear	0.01	0.03	0.05	0.07	0.09	0.11	0.12	0.14	0.16	0.18	0.20	0.22
	Municipal Solid Waste	0.0003	0.0008	0.0012	0.0017	0.0021	0.0025	0.0030	0.0034	0.0038	0.0043	0.0047	0.0051
	Biomass	3.80	8.70	13.60	18.50	23.40	28.31	33.21	38.11	43.01	47.91	52.81	57.71
	Total	5.12	11.72	18.32	24.92	31.52	38.13	44.73	51.33	57.93	64.53	71.14	77.74

*baseline year before introduction of any decentralised RETs

Scenario 1: Fuels for household cooking substituted with RETs.

		Year											
		2011*	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Household Energy demand (TWh)		4.99	13.78	22.10	29.95	37.33	44.24	50.68	56.64	62.14	67.17	71.72	75.80
Global Warming potential (Million tonne CO_2e)	Natural Gas	0.01	0.03	0.05	0.07	0.08	0.10	0.12	0.14	0.15	0.17	0.19	0.21
	Kerosene	0.17	0.38	0.58	0.78	0.96	1.15	1.32	1.49	1.65	1.80	1.95	2.09
	Oil	0.001	0.002	0.003	0.005	0.006	0.007	0.008	0.009	0.011	0.012	0.013	0.014
	Coal	0.15	0.34	0.53	0.72	0.91	1.10	1.29	1.48	1.67	1.86	2.06	2.25
	Biomass	0.10	0.22	0.33	0.43	0.52	0.59	0.65	0.70	0.74	0.77	0.78	0.78
	Total	0.43	0.97	1.50	2.00	2.48	2.95	3.39	3.82	4.23	4.62	4.99	5.34
Primary energy requirements (TWh)	Natural Gas	0.07	0.15	0.24	0.33	0.41	0.50	0.59	0.67	0.76	0.85	0.93	1.02
	Kerosene	0.64	1.43	2.21	2.95	3.67	4.36	5.03	5.67	6.28	6.87	7.43	7.96
	Oil	0.004	0.008	0.013	0.017	0.022	0.027	0.031	0.036	0.040	0.045	0.050	0.054
	Coal	0.44	1.01	1.58	2.15	2.72	3.29	3.86	4.42	4.99	5.56	6.13	6.70
	Wind	0.05	0.81	1.58	2.34	3.11	3.87	4.63	5.40	6.16	6.93	7.69	8.45
	Solar	0.003	2.078	4.153	6.228	8.303	10.378	12.453	14.528	16.603	18.678	20.753	22.828
	Hydro	0.10	0.23	0.37	0.50	0.63	0.76	0.89	1.03	1.16	1.29	1.42	1.55
	Nuclear	0.01	0.03	0.05	0.07	0.09	0.11	0.12	0.14	0.16	0.18	0.20	0.22
	Municipal Solid Waste	0.0003	0.0008	0.0012	0.0017	0.0021	0.0025	0.0030	0.0034	0.0038	0.0043	0.0047	0.0051
	Biomass	3.80	8.31	12.37	15.99	19.16	21.89	24.18	26.02	27.42	28.37	28.88	28.95
	Total	5.12	14.07	22.56	30.57	38.11	45.19	51.79	57.92	63.58	68.77	73.49	77.74

*baseline year before introduction of any decentralised RETs

Scenario 2: Fuels for household lighting substituted with RETs.

		Year											
		2011*	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Household Energy demand (TWh)		4.99	11.73	18.41	25.03	31.59	38.09	44.53	50.90	57.22	63.48	69.67	75.80
Global Warming potential (Million tonne CO_2e)	Natural Gas	0.01	0.03	0.05	0.06	0.08	0.10	0.11	0.13	0.14	0.16	0.17	0.19
	Kerosene	0.17	0.37	0.56	0.74	0.91	1.06	1.20	1.33	1.45	1.55	1.64	1.72
	Oil	0.001	0.002	0.003	0.004	0.006	0.007	0.008	0.009	0.010	0.011	0.012	0.013
	Coal	0.15	0.34	0.52	0.70	0.88	1.05	1.23	1.39	1.56	1.72	1.88	2.04
	Biomass	0.10	0.24	0.37	0.50	0.63	0.77	0.90	1.03	1.16	1.30	1.43	1.56
	Total	0.43	0.98	1.50	2.01	2.51	2.99	3.45	3.90	4.33	4.74	5.14	5.52
Primary energy requirements (TWh)	Natural Gas	0.07	0.15	0.24	0.32	0.40	0.48	0.56	0.63	0.71	0.78	0.85	0.92
	Kerosene	0.64	1.42	2.15	2.83	3.46	4.05	4.59	5.07	5.52	5.91	6.25	6.55
	Oil	0.004	0.008	0.013	0.017	0.021	0.025	0.030	0.034	0.038	0.042	0.045	0.049
	Coal	0.44	1.00	1.55	2.09	2.63	3.15	3.66	4.16	4.65	5.14	5.61	6.07
	Wind	0.05	0.20	0.36	0.51	0.66	0.81	0.96	1.10	1.25	1.39	1.54	1.68
	Solar	0.003	0.273	0.543	0.814	1.084	1.354	1.624	1.894	2.164	2.434	2.704	2.974
	Hydro	0.10	0.23	0.36	0.48	0.61	0.73	0.85	0.96	1.08	1.19	1.30	1.41
	Nuclear	0.01	0.03	0.05	0.07	0.08	0.10	0.12	0.13	0.15	0.17	0.18	0.20
	Municipal Solid Waste	0.0003	0.0008	0.0012	0.0016	0.0020	0.0024	0.0028	0.0032	0.0036	0.0039	0.0043	0.0047
	Biomass	3.80	8.70	13.60	18.50	23.40	28.30	33.20	38.10	43.00	47.90	52.80	57.70
	Total	5.12	12.02	18.86	25.63	32.35	39.00	45.58	52.10	58.56	64.96	71.29	77.56

*baseline year before introduction of any decentralised RETs

Scenario 3: Fuels for household lighting & other appliances substituted with RETs.

		Year											
		2011*	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Household Energy demand (TWh)		4.99	12.00	18.90	25.68	32.34	38.90	45.33	51.66	57.87	63.96	69.94	75.80
Global Warming potential (Million tonne CO_2e)	Natural Gas	0.01	0.03	0.04	0.06	0.07	0.08	0.09	0.09	0.10	0.10	0.10	0.10
	Kerosene	0.17	0.37	0.56	0.74	0.91	1.06	1.20	1.33	1.45	1.55	1.64	1.72
	Oil	0.001	0.002	0.003	0.004	0.005	0.005	0.006	0.006	0.007	0.007	0.007	0.007
	Coal	0.15	0.32	0.48	0.62	0.75	0.85	0.94	1.01	1.07	1.10	1.12	1.12
	Biomass	0.10	0.24	0.37	0.50	0.63	0.77	0.90	1.03	1.16	1.30	1.43	1.56
	Total	0.43	0.96	1.46	1.93	2.36	2.76	3.13	3.47	3.78	4.06	4.30	4.52
Primary energy requirements (TWh)	Natural Gas	0.07	0.15	0.22	0.28	0.34	0.39	0.43	0.46	0.48	0.50	0.51	0.51
	Kerosene	0.64	1.42	2.15	2.83	3.46	4.05	4.59	5.07	5.52	5.91	6.25	6.55
	Oil	0.004	0.008	0.012	0.015	0.018	0.021	0.023	0.024	0.026	0.027	0.027	0.027
	Coal	0.44	0.96	1.44	1.86	2.22	2.54	2.80	3.02	3.18	3.29	3.34	3.35
	Wind	0.05	0.28	0.50	0.72	0.93	1.14	1.34	1.53	1.72	1.91	2.08	2.25
	Solar	0.003	0.510	1.018	1.525	2.031	2.538	3.044	3.549	4.055	4.560	5.064	5.569
	Hydro	0.10	0.22	0.33	0.43	0.52	0.59	0.65	0.70	0.74	0.76	0.77	0.78
	Nuclear	0.01	0.03	0.05	0.06	0.07	0.08	0.09	0.10	0.10	0.11	0.11	0.11
	Municipal Solid Waste	0.0003	0.0007	0.0011	0.0014	0.0017	0.0020	0.0022	0.0023	0.0024	0.0025	0.0026	0.0026
	Biomass	3.80	8.70	13.60	18.50	23.39	28.29	33.18	38.07	42.96	47.85	52.74	57.62
	Total	5.12	12.28	19.31	26.21	32.99	39.63	46.14	52.53	58.78	64.91	70.91	76.77

*baseline year before introduction of any decentralised RETs

A.5.3. Model 3:

Baseline Model.

		Year											
		2011*	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Household Energy demand (TWh)		4.02	8.24	12.47	16.70	20.93	25.16	29.39	33.62	37.85	42.08	46.31	50.54
Global Warming potential (Million tonne CO_2e)	Natural Gas	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.11	0.12
	Kerosene	0.39	0.80	1.21	1.62	2.02	2.43	2.84	3.25	3.66	4.07	4.48	4.89
	Oil	0.001	0.001	0.002	0.003	0.004	0.004	0.005	0.01	0.01	0.01	0.01	0.01
	Coal	0.11	0.22	0.33	0.44	0.56	0.67	0.78	0.90	1.01	1.12	1.23	1.35
	Biomass	0.06	0.12	0.18	0.24	0.30	0.36	0.42	0.48	0.54	0.61	0.67	0.73
	Total	0.56	1.16	1.75	2.34	2.94	3.53	4.12	4.72	5.31	5.90	6.50	7.09
Primary energy requirements (TWh)	Natural Gas	0.05	0.10	0.15	0.20	0.25	0.30	0.36	0.41	0.46	0.51	0.56	0.61
	Kerosene	1.48	3.04	4.59	6.15	7.71	9.27	10.82	12.38	13.94	15.50	17.05	18.61
	Oil	0.003	0.005	0.008	0.011	0.013	0.016	0.019	0.022	0.024	0.027	0.030	0.032
	Coal	0.32	0.66	0.99	1.33	1.66	2.00	2.34	2.67	3.01	3.34	3.68	4.02
	Wind	0.04	0.07	0.11	0.15	0.19	0.23	0.27	0.30	0.34	0.38	0.42	0.46
	Solar	0.002	0.004	0.006	0.008	0.010	0.012	0.014	0.016	0.019	0.021	0.023	0.025
	Hydro	0.07	0.15	0.23	0.31	0.39	0.46	0.54	0.62	0.70	0.77	0.85	0.93
	Nuclear	0.01	0.02	0.03	0.04	0.05	0.06	0.08	0.09	0.10	0.11	0.12	0.13
	Municipal Solid Waste	0.0002	0.0005	0.0008	0.0010	0.0013	0.0015	0.0018	0.0021	0.0023	0.0026	0.0028	0.0031
	Biomass	2.14	4.39	6.64	8.88	11.13	13.38	15.63	17.88	20.13	22.38	24.63	26.88
	Total	4.11	8.43	12.76	17.09	21.41	25.74	30.06	34.39	38.72	43.04	47.37	51.70

*baseline year before introduction of any decentralised RETs

Scenario 1: Fuels for household cooking substituted with RETs.

		Year											
		2011*	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Household Energy demand (TWh)		4.02	9.26	14.31	19.15	23.78	28.22	32.45	36.47	40.29	43.91	47.33	50.54
Global Warming potential (Million tonne CO_2e)	Natural Gas	0.01	0.02	0.03	0.04	0.05	0.06	0.07	0.08	0.09	0.10	0.11	0.12
	Kerosene	0.39	0.80	1.21	1.62	2.02	2.43	2.84	3.25	3.66	4.07	4.48	4.89
	Oil	0.001	0.001	0.002	0.003	0.004	0.004	0.005	0.006	0.006	0.007	0.008	0.009
	Coal	0.11	0.22	0.33	0.44	0.56	0.67	0.78	0.90	1.01	1.12	1.23	1.35
	Biomass	0.06	0.11	0.16	0.21	0.25	0.28	0.31	0.33	0.35	0.36	0.36	0.36
	Total	0.56	1.15	1.73	2.31	2.88	3.45	4.01	4.56	5.11	5.66	6.20	6.73
Primary energy requirements (TWh)	Natural Gas	0.05	0.10	0.15	0.20	0.25	0.30	0.36	0.41	0.46	0.51	0.56	0.61
	Kerosene	1.48	3.04	4.59	6.15	7.71	9.27	10.82	12.38	13.94	15.50	17.05	18.61
	Oil	0.003	0.005	0.008	0.011	0.013	0.016	0.019	0.022	0.024	0.027	0.030	0.032
	Coal	0.32	0.66	0.99	1.33	1.66	2.00	2.34	2.67	3.01	3.34	3.68	4.02
	Wind	0.04	0.38	0.73	1.07	1.42	1.76	2.11	2.45	2.80	3.14	3.49	3.84
	Solar	0.002	0.914	1.826	2.738	3.649	4.561	5.473	6.385	7.297	8.209	9.121	10.033
	Hydro	0.07	0.15	0.23	0.31	0.39	0.46	0.54	0.62	0.70	0.77	0.85	0.93
	Nuclear	0.01	0.02	0.03	0.04	0.05	0.06	0.08	0.09	0.10	0.11	0.12	0.13
	Municipal Solid Waste	0.0002	0.0005	0.0008	0.0010	0.0013	0.0015	0.0018	0.0021	0.0023	0.0026	0.0028	0.0031
	Biomass	2.14	4.19	6.03	7.68	9.12	10.35	11.39	12.22	12.84	13.26	13.48	13.50
	Total	4.11	9.45	14.59	19.53	24.26	28.79	33.12	37.24	41.16	44.88	48.39	51.70

*baseline year before introduction of any decentralised RETs

Scenario 2: Fuels for household lighting substituted with RETs.

		Year											
		2011*	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Household Energy demand (TWh)		4.02	9.07	13.95	18.68	23.24	27.63	31.86	35.92	39.82	43.56	47.13	50.54
Global Warming potential (Million tonne CO_2e)	Natural Gas	0.01	0.02	0.03	0.04	0.05	0.05	0.06	0.07	0.07	0.08	0.08	0.09
	Kerosene	0.39	0.76	1.10	1.39	1.66	1.88	2.07	2.22	2.33	2.40	2.44	2.44
	Oil	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01
	Coal	0.11	0.21	0.31	0.41	0.50	0.58	0.66	0.73	0.79	0.85	0.91	0.95
	Biomass	0.06	0.12	0.18	0.24	0.30	0.36	0.42	0.48	0.54	0.61	0.67	0.73
	Total	0.56	1.11	1.62	2.08	2.50	2.88	3.21	3.50	3.75	3.95	4.10	4.22
Primary energy requirements (TWh)	Natural Gas	0.05	0.10	0.14	0.19	0.23	0.26	0.30	0.33	0.36	0.39	0.41	0.43
	Kerosene	1.48	2.90	4.18	5.31	6.31	7.16	7.87	8.44	8.87	9.16	9.30	9.31
	Oil	0.003	0.005	0.008	0.010	0.012	0.014	0.016	0.018	0.019	0.021	0.022	0.023
	Coal	0.32	0.64	0.94	1.22	1.49	1.73	1.96	2.17	2.37	2.54	2.70	2.84
	Wind	0.04	0.32	0.60	0.88	1.16	1.44	1.71	1.98	2.25	2.52	2.79	3.05
	Solar	0.002	0.739	1.475	2.212	2.948	3.684	4.421	5.157	5.892	6.628	7.364	8.100
	Hydro	0.07	0.15	0.22	0.28	0.34	0.40	0.45	0.50	0.55	0.59	0.63	0.66
	Nuclear	0.01	0.02	0.03	0.04	0.05	0.06	0.06	0.07	0.08	0.08	0.09	0.09
	Municipal Solid Waste	0.0002	0.0005	0.0007	0.0009	0.0011	0.0013	0.0015	0.0017	0.0018	0.0020	0.0021	0.0022
	Biomass	2.14	4.39	6.63	8.88	11.13	13.38	15.62	17.87	20.12	22.36	24.61	26.85
	Total	4.11	9.25	14.23	19.03	23.66	28.13	32.42	36.55	40.51	44.29	47.91	51.36

*baseline year before introduction of any decentralised RETs

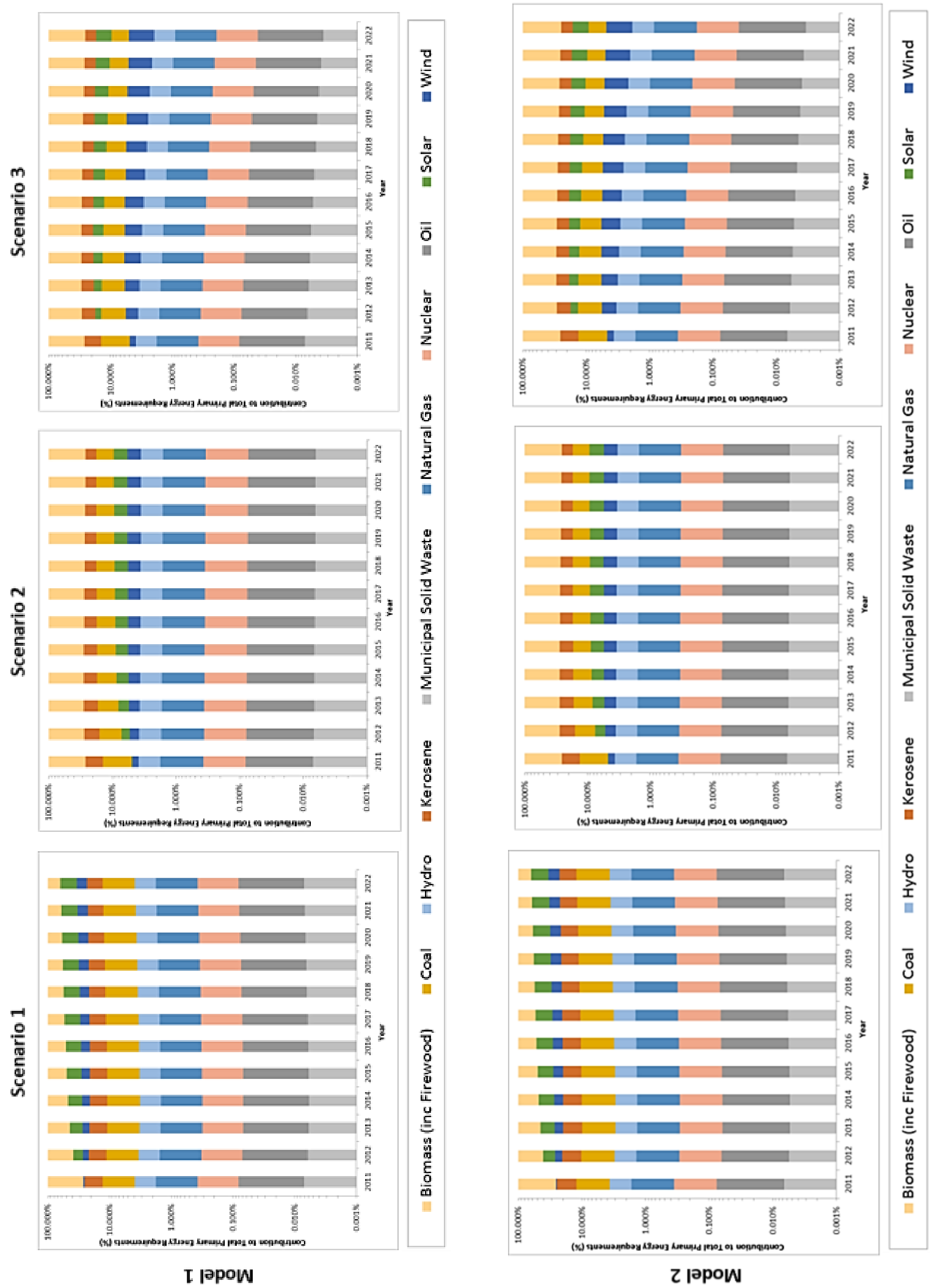
Scenario 3: Fuels for household lighting & other appliances substituted with RETs.

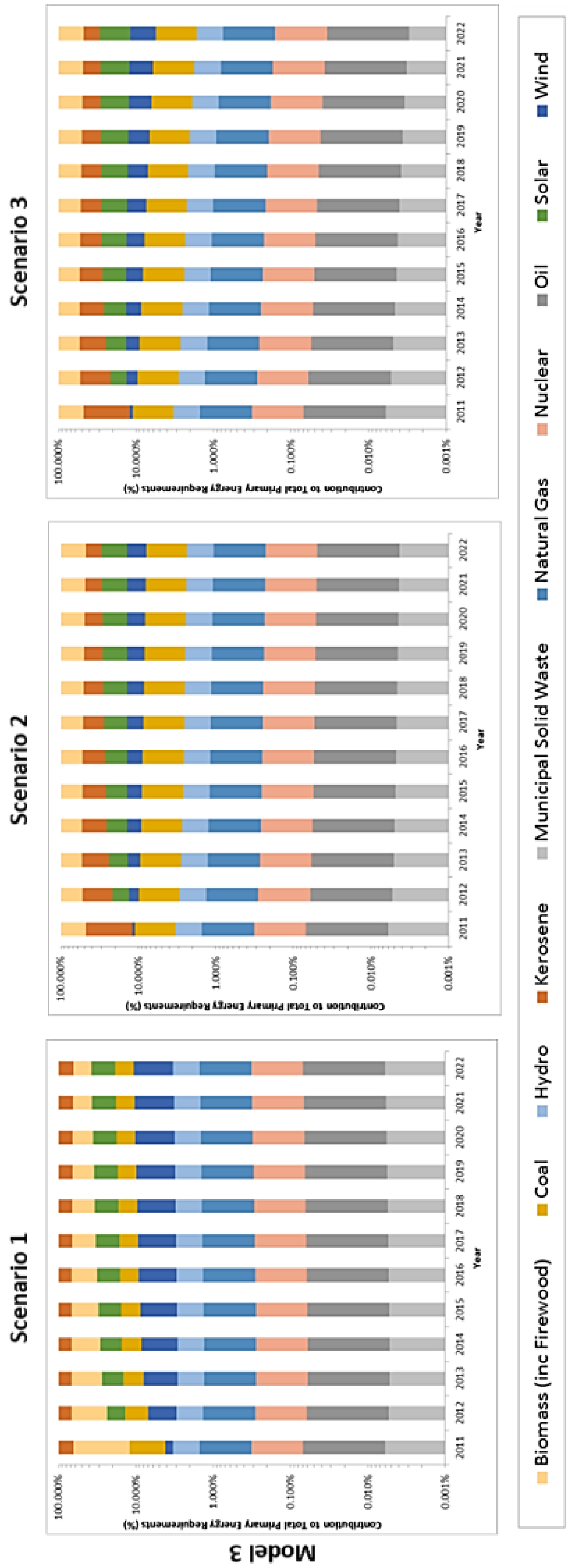
		Year											
		2011*	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Household Energy demand (TWh)		4.02	9.15	14.10	18.87	23.46	27.87	32.10	36.15	40.02	43.71	47.21	50.54
Global Warming potential (Million tonne CO_2e)	Natural Gas	0.01	0.02	0.03	0.04	0.04	0.05	0.05	0.06	0.06	0.06	0.06	0.06
	Kerosene	0.39	0.76	1.10	1.39	1.66	1.88	2.07	2.22	2.33	2.40	2.44	2.44
	Oil	0.001	0.001	0.002	0.002	0.003	0.003	0.004	0.004	0.004	0.004	0.004	0.004
	Coal	0.11	0.21	0.30	0.38	0.46	0.52	0.57	0.61	0.64	0.66	0.67	0.67
	Biomass	0.06	0.12	0.18	0.24	0.30	0.36	0.42	0.48	0.54	0.61	0.67	0.73
	Total	0.56	1.11	1.61	2.06	2.46	2.81	3.11	3.37	3.58	3.74	3.85	3.91
Primary energy requirements (TWh)	Natural Gas	0.05	0.10	0.14	0.17	0.21	0.24	0.26	0.28	0.29	0.30	0.31	0.31
	Kerosene	1.48	2.90	4.18	5.31	6.31	7.16	7.87	8.44	8.87	9.16	9.30	9.31
	Oil	0.003	0.005	0.007	0.009	0.011	0.012	0.014	0.015	0.015	0.016	0.016	0.016
	Coal	0.32	0.63	0.90	1.15	1.36	1.55	1.70	1.82	1.91	1.98	2.01	2.01
	Wind	0.04	0.34	0.65	0.95	1.25	1.54	1.83	2.12	2.40	2.68	2.95	3.23
	Solar	0.002	0.811	1.620	2.429	3.238	4.047	4.855	5.663	6.471	7.279	8.087	8.894
	Hydro	0.07	0.14	0.21	0.27	0.32	0.36	0.39	0.42	0.44	0.46	0.46	0.47
	Nuclear	0.01	0.02	0.03	0.04	0.04	0.05	0.05	0.06	0.06	0.06	0.06	0.06
	Municipal Solid Waste	0.0002	0.0005	0.0007	0.0009	0.0010	0.0012	0.0013	0.0014	0.0015	0.0015	0.0015	0.0015
	Biomass	2.14	4.38	6.63	8.88	11.13	13.37	15.62	17.86	20.10	22.35	24.59	26.83
	Total	4.11	9.33	14.36	19.20	23.86	28.32	32.59	36.68	40.57	44.28	47.79	51.12

*baseline year before introduction of any decentralised RETs

Appendix 6: Changes Over Time Of Primary Energy Consumption Needed To Meet Total Rural Household Energy Demand Resulting From The Introduction Of Decentralised Rets Under Varying Fuel Substitution Scenarios Compared To Baseline Models.

n.b. The first column in each graph represents the start year contributions of each fuel source under the baseline scenario for that model.




Model 3
Scenario 1
Scenario 2
Scenario 3
Contribution to Total Primary Energy Requirements (%)
Year
Biomass (inc Firewood)
Coal
Hydro
Kerosene
Municipal Solid Waste
Natural Gas
Nuclear
Oil
Solar
Wind

Appendix 7: Rural Energy Survey Implemented In Orissa

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Interviewer initials________________ Date:_____/_____/_____

HOUSEHOLD ENERGY CONSUMPTION SURVEY – RESPONSE SHEET

State: ________________________ District: ________________________

Village: ____

SECTION 1: RESPONDENT DETAILS

1.1 Respondent age: ☐ Under 16 ☐ 16 – 20 ☐ 21 – 25 ☐ 26 – 30 ☐ 31 – 35 ☐ 36 – 40 ☐ 41 – 45 ☐ 46 – 50 ☐ 51 – 55 ☐ 56 – 60 ☐ 61+

1.2 Gender: ☐ Male ☐ Female

SECTION 2: HOUSEHOLD INFORMATION

2.1 Number of permanent occupants in the household: ________________

2.2 Number of rooms in the household: ________________

2.3 Do you keep livestock? ☐ Yes ☐ No *If Yes list all and how many:*

________ Nº. ______ ________ Nº. ______
________ Nº. ______ ________ Nº. ______
________ Nº. ______ ________ Nº. ______

2.4 Do you grow your own crops? ☐ Yes ☐ No

If Yes list all and area ________ Area ________
________ Area ________
________ Area ________
________ Area ________

2.5 Is the respondent head of the household? ☐ Yes ☐ No

If No, who is? The respondents… (Tick one)

☐ Father ☐ Mother ☐ Husband ☐ Wife
☐ Son ☐ Brother ☐ Daughter ☐ Sister
☐ Other relative: ________________

2.6 Is the head of the household responsible for deciding household fuel use? ☐ Yes ☐ No

If No, who is? ________________________

☐ Shared responsibility
☐ No one's responsibility

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Household construction

2.7 What material is the roof mostly made of? *(Name one only)* ________________

2.8 What material are the walls mostly made of? *(Name one only)* ________________

2.9 What material is the floor? *(Name one only)* ________________

2.10 How many levels is:
1) Your home spread over? ________
2) The whole building? ________
Which floor do you live on? ________

2.11 How many entrances are there into the house? ________________

2.12 What material covers these entrances? ________________

2.13 How many windows are there in the house? ________________

If 1 or more windows: Are these windows always open? ☐ Yes ☐ No

SECTION 3: ENERGY CONSUMPTION

Energy for lighting:

3.1 Which of these do you use as your **MAIN** source of lighting? *(Tick one only)*

☐ Paraffin/ Kerosene ☐ Electricity ☐ Firewood/Biomass
☐ LP Gas ☐ Candles ☐ Other *(explain)* ________________

3.2 Reasons for use? *(Tick all that apply)*

☐ Cheap ☐ Easily available ☐ Easy to use ☐ Cannot afford other fuels
☐ Familiar fuel ☐ Only fuel available ☐ Other *(List)* ________________

3.3 Are you happy with this fuel supply? ☐ Yes ☐ No

If No, why not? (Tick all that apply)

☐ Smoky ☐ Unsafe ☐ Health concerns ☐ Takes too long to burn
☐ Expensive ☐ Unreliable ☐ Other *(Explain)* ________________

3.4 What other energy sources, if any, do you use for lighting? *(Please tick at least one)*

☐ Paraffin\Kerosene ☐ Electricity ☐ Firewood/Biomass
☐ LP Gas ☐ Candles ☐ No other source used *(Skip to question 3.6)*
☐ Other *(explain)* ________________

3.5 When is this other source used over your main supply? ________________

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3.6 What other energy sources are available **BUT NOT** used, and **WHY NOT**. *(Please tick at least one)*

	Reason for NOT using					
Available Fuel	Smoky	Unsafe	Unreliable	Expensive	**Other** (*Please provide details*)	No other available
Example: Paraffin		✓		✓	*Difficult to store*	
Paraffin\Kerosene						
LP Gas						
Electricity						
Firewood/Biomass						
Candles						
Other (give details)						
No other available						

Use of lighting:

3.7 Do you typically need to use non-natural lighting in the morning during:

Winter: ☐ No ☐ Yes, *if so* for approximately how long? ____________ hours ________ minutes per **day**

Summer: ☐ No ☐ Yes, *if so* for approximately how long? ____________ hours ________ minutes per **day**

3.8 Do you use non-natural lighting at night during:

Winter: ☐ No ☐ Yes, *if so* for approximately how long? ____________ hours ________ minutes per **day**

Summer: ☐ No ☐ Yes, *if so* for approximately how long? ____________ hours ________ minutes per **day**

3.9 Are the lights at night used to allow work to be carried out? ☐ Yes ☐ No

If Yes: How many people work at night? ______________

How many hours do they typically work for? ____________________ hours

3.10 Which of the following light sources do you use? *(Tick all that apply)*

☐ Electric lights *If so how many?* _________

☐ Open fire *If so how many?* _________ *How much fuel do you use per 24hours?* ___________ kg

☐ Fuel lamp/lantern *If so how many?* _________ *How much fuel do you use per 24hours?* ___________ L

☐ Other ______________________ *If so how many?* _________ *How much fuel do you use per 24hours?* ___________ ______

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3.11 *Note: If the respondent **Did Not** indicate the use electric lights in question 3.10, you may skip this question.*

For each electric light please specify how many of each type you have and what the wattage is. *See the example below.*

	Light wattage											
Light type	100	80	60	50	40	35	**Other** (*please specify*)					***Don't know***
Example: Filament bulbs	*2*				*1*							
Filament bulbs												
Energy saving (CFLs) lights												
Halogen lights												
LED lamps												
Fluorescent (Tube) lights												
Other, please specify:												

Energy for cooking:

3.12 Approximately how much time is spent cooking every 24 hours? ____________ hours ____________ minutes

3.13 Which of these do you use as your **MAIN** fuel for cooking? *(Tick one only)*

☐ Paraffin\Kerosene ☐ Electricity ☐ Firewood/Biomass

☐ LP Gas ☐ Other (explain) ____

____

3.14 Reason for use? *(Tick all that apply)*

☐ Cheap ☐ Easily available ☐ Easy to use ☐ Can't afford other fuels

☐ Familiar fuel ☐ Only fuel available ☐ Other *(List)* ________________________________

____

3.15 Are you happy with this fuel supply? ☐ Yes ☐ No

If No, why not?

☐ Smoky ☐ Unsafe ☐ Health concerns ☐ Takes too long to burn

☐ Expensive ☐ Unreliable ☐ Other *(Explain)* ________________________________

____

3.16 What other energy sources, if any do you use for this service? *(Please tick at least one)*

☐ Paraffin\Kerosene ☐ Electricity ☐ Firewood/Biomass

☐ LP Gas ☐ Candles ☐ No other source used (*Skip to question 3.18*)

☐ Other (list) ____

3.17 When is this other source used over your main supply? ____

____

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3.18 Of the fuels you use for cooking, how much do you use of each per day/week/month? *(Please specify)*

Fuels Used	Amount Consumed per day/week: Kg	Litres	Gallon	Other (*please specify*)	Other (*please specify*)	Other (*please specify*)	Don't know	*Delete as appropriate*
Example: Paraffin		3						~~Day~~ / Week / ~~Month~~
Paraffin\Kerosene								Day / Week / Month
LP Gas								Day / Week / Month
Firewood/Biomass								Day / Week / Month
Candles								Day / Week / Month
Other (*give details*)								Day / Week / Month
								Day / Week / Month
								Day / Week / Month

3.19 What other energy sources are available **BUT NOT** used, and **WHY NOT**. *(Please tick at least one)*

Available Fuel	Reason for NOT using: Smoky	Unsafe	Unreliable	Expensive	Not easily available	Other (*Please provide details*)	No other available
Example: Paraffin		✓		✓		*Difficult to store*	
Paraffin\Kerosene							
LP Gas							
Electricity							
Firewood/Biomass							
Candles							
Other (give details)							
No other available							

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Energy for heating and cooling:

3.20 Do you typically need to **heat** the house during:

Winter: ☐ No ☐ Yes, *if so* for approximately how long? ____________ hours ________ minutes per **day**

Summer: ☐ No ☐ Yes, *if so* for approximately how long? ____________ hours ________ minutes per **day**

*If the respondent answered **NO** to **BOTH** parts skip to question 3.28*

3.21 Which of these do you use as your **MAIN** fuel for heating? *(Tick one only)*

☐ Paraffin\Kerosene ☐ Electricity ☐ Firewood/Biomass

☐ LP Gas ☐ Other (list) ________________________________

3.22 Reason for use? *(Tick all that apply)*

☐ Cheap ☐ Easily available ☐ Easy to use ☐ Can't afford other fuels

☐ Familiar fuel ☐ Only fuel available ☐ Other *(Explain)* ____________________

3.23 Are you happy with this fuel supply? ☐ Yes ☐ No

If No, why not?

☐ Smoky ☐ Unsafe ☐ Health concerns ☐ Takes too long to burn

☐ Expensive ☐ Unreliable ☐ Other *(Explain)* ____________________

3.24 What other energy sources, if any, do you use for this service? *(Please tick at least one)*

☐ Paraffin\Kerosene ☐ Electricity ☐ Firewood/Biomass

☐ LP Gas ☐ Candles ☐ No other source used (*Skip to question 3.26*)

☐ Other *(Explain)* ________________________________

3.25 When is this other source used over you main supply? ________________________________

3.26 Of the fuels you use for heating how much do you consume of each per day/week/month? *(Please specify)*

Fuels Used	Amount Consumed per day/week: Kg	Litres	Gallon	Other (*please specify*)	Other (*please specify*)	Other (*please specify*)	Don't know	*Delete as appropriate*
Example: Paraffin		3						~~Day~~ / Week / ~~Month~~
Paraffin\Kerosene								Day / Week / Month
LP Gas								Day / Week / Month
Firewood/Biomass								Day / Week / Month
Candles								Day / Week / Month
Other (*give details*)								Day / Week / Month
								Day / Week / Month
								Day / Week / Month

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3.27 What other energy sources are available **BUT NOT** used, and **WHY NOT**. *(Please tick at least one)*

Available Fuel	Smoky	Unsafe	Unreliable	Expensive	Not easily available	Other (*Please provide details*)	No other available
	Reason for NOT using						
Example: Paraffin		✓		✓		*Difficult to store*	
Paraffin\Kerosene							
LP Gas							
Electricity							
Firewood/Biomass							
Candles							
Other (give details)							
No other available							☐

3.28 Over 24 hours how long do you typically use fans, air conditioning etc. to **cool** the household?

In the winter? Approximately ______________ hours ___________ minutes

In the summer? Approximately ______________ hours ___________ minutes

3.29 Is equipment used for household cooling powered by electricity? *(Please tick at least one)*

☐ Yes ☐ No *If No, how?* ________________________________

Other energy resource usage:

3.30 Do you require any other energy resource to carry out any other tasks? ☐ Yes ☐ No

If No skip to question 3.32

3.31 *If Yes what tasks and what energy resource or fuel(s) do you use? (Please list and give details)*

Task	Energy/Fuel(s) used

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If the respondent indicated that they **USE** or have **ACCESS** to **ELECTRICITY** in any of the above questions please answer the following. *If NOT skip to Section 4.*

3.32 How long has the household had access to electricity? ______________________ Years/Months *(Delete as appropriate)*

3.33 How **is** or **could** electricity be supplied to the household?

☐ Batteries

☐ National/State grid supply

☐ Local village generator

How is this fuelled? ☐ LP Gas ☐ Diesel ☐ Petrol ☐ Paraffin\Kerosene

☐ Wood ☐ Other ________________________________

☐ Personal generator

How is this fuelled? ☐ LP Gas ☐ Diesel ☐ Petrol ☐ Paraffin\Kerosene

☐ Wood ☐ Other ________________________________

☐ Other ____

____

SECTION 4: FUEL CONSUMPTION

4.1 How much do you spend on fuel each week or month? Please give details of all the fuels you use.

Fuel	Approximate Spend	
	Weekly	Monthly
	₹ (Rs)	₹ (Rs)
	₹ (Rs)	₹ (Rs)
	₹ (Rs)	₹ (Rs)
	₹ (Rs)	₹ (Rs)
	₹ (Rs)	₹ (Rs)
	₹ (Rs)	₹ (Rs)
	₹ (Rs)	₹ (Rs)
	₹ (Rs)	₹ (Rs)

4.2 How does the household's fuel usage differ during the winter in comparison to the summer?

☐ Higher ☐ Same ☐ Lower ☐ Do not know

4.3 Do you buy all the fuel you use?

☐ Yes *Skip to question 4.6* ☐ No

4.4 Where does this "free" fuel come from? ________________________________

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4.5 What type of fuel do you get for free and how much? *(Please list all and give amounts and units)*

Fuel	Amount *(Please give units)*	Delete as appropriate
		Day/Week/Month
		Day/Week/Month
		Day/Week/Month
		Day/Week/Month

4.6 Which of the following appliances do you have, would like to have, or don't want?

Oven: ☐ Want ☐ Have ☐ Do not want *Why?* ____________

Kettle: ☐ Want ☐ Have ☐ Do not want *Why?* ____________

Refrigerator: ☐ Want ☐ Have ☐ Do not want *Why?* ____________

Freezer: ☐ Want ☐ Have ☐ Do not want *Why?* ____________

Radio: ☐ Want ☐ Have ☐ Do not want *Why?* ____________

Television: ☐ Want ☐ Have ☐ Do not want *Why?* ____________

Telephone: ☐ Want ☐ Have ☐ Do not want *Why?* ____________

Air conditioning: ☐ Want ☐ Have ☐ Do not want *Why?* ____________

Mechanical fan: ☐ Want ☐ Have ☐ Do not want *Why?* ____________

SECTION 5: HOUSEHOLD INCOME & EXPENSES

5.1 For *each* member of the household outline their contribution to household income, if any.

Family Member	Occupation/Job	Approximate work hours per week	Weekly income
Example: Son 1	*Labourer*	*56*	*₹(Rs) 200*
Respondent			₹ (Rs)
			₹ (Rs)
			₹ (Rs)
			₹ (Rs)
			₹ (Rs)
			₹ (Rs)
			₹ (Rs)
			₹ (Rs)
			₹ (Rs)
			₹ (Rs)
			₹ (Rs)
			₹ (Rs)
			₹ (Rs)
			₹ (Rs)
			₹ (Rs)

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5.2 Are there any other sources of household income? ☐ Yes ☐ No

If *Yes*: How much: ₹ (Rs) ____________ Week/Month/Year *(Delete as appropriate)*

5.3 How else do all members of the family spend their time each week when not working? *(Answer in hours)*

	Activity (hours per week)								
Family Member	Firewood collection	Water collection	Education	Recreation	Other (specify)	Other (specify)	Other (specify)	Other (specify)	Other (specify)
Example: Son 1			*5*	*3*					
Respondent									

5.4 How much is spent each month on necessities for the household?

Item/Activity	Monthly/Weekly/Yearly expense (delete as appropriate)	
Example: Food	*₹(Rs) 100*	Week/~~Month/Year~~
Food	₹ (Rs)	Week/Month/Year
Education fees	₹ (Rs)	Week/Month/Year
Transport	₹ (Rs)	Week/Month/Year
Rent	₹ (Rs)	Week/Month/Year
Clothes	₹ (Rs)	Week/Month/Year
Health care	₹ (Rs)	Week/Month/Year
	₹ (Rs)	Week/Month/Year
	₹ (Rs)	Week/Month/Year
	₹ (Rs)	Week/Month/Year
	₹ (Rs)	Week/Month/Year
	₹ (Rs)	Week/Month/Year
	₹ (Rs)	Week/Month/Year

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SECTION 6: VIEWS ON RENEWABLE ENERGY

6.1 Are you aware of the term "renewable or sustainable energy"? ☐ Yes ☐ No *If No go to question 6.3*

What do you think it means? ____________________

____

☐ Does not wish to give definition

6.2 Can you name any examples you have heard of? *(Please tick all that apply)*

☐ Biodiesel ☐ Biogas ☐ Bioethanol ☐ Solar power

☐ Tidal power ☐ Wind power ☐ Geothermal ☐ Hydroelectricity

☐ Cannot think of any ☐ Other ____________________

6.3 Have you heard of any of the following means of energy generation? *(Please tick all that apply)*

☐ Solar panels ☐ Wind turbines ☐ Biodiesel ☐ Bioethanol ☐ Bio digester (biogas)

☐ Tidal energy ☐ Hydroelectricity ☐ Geothermal ☐ Haven't heard of any *(If so Skip to question 6.9)*

6.4 Of the energies sources you have identified, which do you think, if any, would be of benefit to your village or individual household as a means of supplying energy? *(Tick all that apply)*

☐ Biodiesel ☐ Biogas ☐ Bioethanol ☐ Solar power

☐ Tidal power ☐ Wind power ☐ Geothermal ☐ Hydroelectricity

☐ Other ____________________

☐ Do not think any would provide a benefit. *Why?* ____________________

____________________ *(Skip to question 6.6)*

6.5 Why do you think these sources would be of benefit?

Energy source	Reason for choice

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6.6 Do you have a preference of one of these energy sources over the others?

☐ Yes ☐ No

If Yes, please specify which: ____________________

Why? ____________________

6.7 Do you think that communities like your own should be provided with these types of alternative energy supplies?

☐ Yes ☐ No

Why? ____________________

6.8 Do you think these types of energy should be used over current means of energy provision?

☐ Yes ☐ No

Why? ____________________

6.9 If the cost of using these sources was the same as your current supply would you consider switching over if:

You knew it was helping protect the local environment? ☐ Yes ☐ No

You knew it was safer and more reliable? ☐ Yes ☐ No

*If the respondent answers No to **BOTH** questions skip to question 6.11*

6.10 Would you pay slightly more for energy from renewable or sustainable sources if:

You knew it was helping protect the local environment? ☐ Yes ☐ No

You knew it was safer and more reliable? ☐ Yes ☐ No

6.11 Would you pay part of the set up cost for a renewable or sustainable energy supply if it meant:

Cheaper supply? ☐ Yes ☐ No

Safer supply? ☐ Yes ☐ No

More reliable supply? ☐ Yes ☐ No

6.12 What incentives would encourage you to adopt the use of renewable/sustainable energies?

____

____

____

6.13 What problems do you think might occur during the setup and operation of these sustainable energy supplies?

Set up: ____________________

____

Operation: ____________________

____

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